UTILITY SPONSORED CONSERVATION PROGRAMS: AN ECONOMIC WELFARE ANALYSIS

BY

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Abstract of Dissertation Presented to the Graduate School of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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A major concern of public electric utilities is the proper level of energy conservation investment that households should make. Engineering cost studies indicate that the average household does not minimize its long-run total cooling and heating costs. To rectify the situation, some public utilities have attempted to induce greater energy conservation through programs that subsidize the purchase of high-efficiency air-conditioning and heating systems and ceiling insulation.

A major question mark in the effectiveness of such programs is the reaction that households might have. Lower heating and cooling costs might induce more intensive appliance usage, thus counteracting the conservation of energy.

Perhaps a better measure of evaluating such programs would be economic welfare. Toward this goal, a model of comfort consumption is devised. The major achievement of this model is the development of a demand function with a non-linear budget constraint. Roy's identity and Shephard's lemma are also generalized for the non-linear case.

Using a data base from an experiment conducted by the Florida Power and Light Company, a Marshallian-type demand function and expenditure function are estimated. From these estimates, it is determined that the change in consumer's surplus resulting from such studies would be only 3% greater than the potential cost savings in energy. More exact measures of welfare, the compensating variation and equivalent variation, were found to be within 1% of the change in consumer's surplus. Furthermore, the change in consumer's surplus was far less than the amount necessary to make such conservation programs economically efficient or cost-effective.

CHAPTER I

INTRODUCTION

1.1. Outline

Energy conservation has been a stated national objective for well over a decade. A number of programs have been initiated to achieve this goal. From import tariffs, tax incentives and speed limit reductions, to conservation programs sponsored by public utilities, these programs press upon the American economy on a daily basis.

The desirability and performance of these programs must be determined by some evaluation criterion. One possible criterion that appeals to many economists, yet has been rarely applied to these programs, is economic welfare. A determination of just how efficient these programs are, both allocatively and productively, may provide valuable information that can determine the optimal level of resources we should devote to these programs.

This dissertation attempts to measure the welfare effectiveness of utility-sponsored conservation programs using data gathered from an experiment conducted by the Florida Power and Light Company (FP&L). The FP&L experiment was an attempt to determine just how cost effective more

technologically advanced heating and cooling appliances would be in actual practice.

Chapter I explains what conservation programs are and how they have been typically evaluated in the past. A brief discussion of the concept and general approach of the model follows. Chapter II surveys the related academic literature. Chapter III formally develops the model to be applied. Chapter IV describes in detail the FP&L experiment and data set. Chapter V applies the data to the model and estimates the parameters. Chapter VI draws specific conclusions based on the findings of Chapter V and defines the scope for further research.

1.2. Conservation Programs: What They Are and Why They Are Pursued

There are many sponsors of conservation programs. The federal government is a major sponsor by way of tax incentives and import tariffs. The National Energy Conservation Policy Act and subsequent related legislation such as the Energy Security Act encourage residential energy conservation.

These federal programs attempt to diminish the level of domestic energy consumption through means other than and in addition to the price-directed market economy. An economic justification for such programs could be the presence of a negative externality associated with energy consumption. After the Arab oil embargo of 1973, the dependence on foreign producers became a source of national concern. Due

to this externality, the private cost of production might not reflect the total resource cost to society. Under these circumstances, a level of production and consumption that exceeds the optimum (most efficient level) may result. It therefore would be justifiable on efficiency grounds for the government to interfere with the workings of the free market.

Utility-sponsored conservation programs usually take the form of rebates on investment cost, home weatherization (caulking, window-proofing, etc.) and home energy audits. Because of its relative importance, energy used to produce residential indoor thermal comfort (space heating and cooling) is a main target of these programs. Stobaugh and Yergin (1979) report that space heating and cooling account for approximately 65% of total household energy consumption. Frieden and Baker (1983) report that energy used within the home accounts for more than one-fifth of total energy consumption in the United States.

In addition to its large relative share of national energy consumption, residential thermal comfort is a likely target because of the great potential gains in conserved energy that are technically feasible. There has been substantial advancement in the past decade in the productive efficiency of ceiling and wall insulation, air-conditioners and heat-pumps. Yet households seem to lag in response to these technological advancements. Numerous studies have

come to this conclusion (see Frieden and Baker, 1983; Stern, 1984; Stobaugh and Yergin, 1979; Messenger, 1984).

The reason why rational households do not minimize their cost is unclear. One possible answer is the cost of information. It may not pay for a household to invest the time and effort to determine the best conservation measures for its situation. Johnson and Kaserman (1983) report that for the United States housing market, energy-saving durable good investments do not seem to be fully capitalized in the price of the house. Households that are uncertain of the duration of their occupancy may not find it cost effective to invest in conservation. Whatever the reason, there would be a definite gain in efficiency if households were directed to employ a more cost-effective combination of comfort producing inputs.

Many representatives of public utilities will cite, as motivation for such utility-sponsored programs, improved customer relations and government direction (see Parsons, 1982), rather than profit of societal welfare motives.

A possible motivation for utilities is the potential of economizing on generating capacity by supplying households with conservation capital. Marino and Sicilian (1982) demonstrate that under the typical regulated rate-of-return on investment constraint, utilities will tend to under-invest in conservation measures. Their technique is to compare the results of charging customers for the electricity provided and the results of charging customers directly

for the commodity produced with the electricity (i.e., warmth). Even inclusion of the conservation capital in the utilities rate base will not give sufficient incentives.

Marino and Sicilian offer two possible solutions. One is to allow a greater rate of return for conservation investment than for capacity investment. Another possible solution is to set up a competitive industry for the provision of conservation measures. Both solutions would render indeterminate efficiency results.

1.3. Evaluating Conservation Programs

Energy conservation (the amount of energy saved) is the prime objective of such programs. An obvious criterion by which to evaluate these programs is just how much energy has been conserved. The projected savings of increased conservation are as high as 30 to 40 percent (see Stern, 1984; Frieden and Baker, 1983; Messenger, 1984).

Yet these projections implicitly assume that households consume a constant amount of end-use services regardless of the cost. In economic terms, they are implicitly assuming a perfectly inelastic demand for end-use services. As the cost of producing the service (the "shadow price") is reduced by conservation measures, the quantity consumed is unchanged.

Consumption theory tells us that utility maximizing households make decisions "on the margin." That is, they consume a commodity at the level where the price equals the

marginal benefit. If marginal utility is diminishing in consumption, then reductions in the price of a commodity should lead to increases in its consumption.

As it relates to conservation programs, households which experience a decrease in their electricity bills may choose to substitute some or all of their cost savings for increased levels of thermal comfort. Such consumer utility maximizing behavior might mitigate the energy savings of conservation programs.

Perhaps a more justifiable evaluation criterion than "cost effectiveness" would be economic welfare. The inefficiency arises from households not employing the cost minimizing levels of capital and energy. By lowering the cost of thermal comfort, the welfare of the household is increased, whether they choose to consume a higher level of comfort or not.

The standard welfare measures of consumer's surplus, compensating variations and equivalent variation can be used. The general idea is to estimate a "demand for thermal comfort" function, using the marginal cost of producing comfort as the "price." From this demand function, we can calculate the gain to the households of conservation programs and subtract from that the cost of the programs.

From these calculations, we should be able to test the hypothesis that households are not minimizing the cost of comfort. We also should be able to determine the amount of

resources that can be efficiently devoted to energy conservation.

CHAPTER II

SURVEY OF RELATED LITERATURE

2.1. Introduction

The literature that most closely relates to this dissertation falls into three main classifications: household production theory, consumer durable and electricity demand, and end-use demand.

Household production theory deals with situations where the consuming household produces what it consumes. Since thermal indoor comfort is "produced" by each household, its applicability to the household production theory is obvious.

Consumer durables and energy are purchased as inputs into this productive process. The household production theory has been used extensively to explain the demand for these inputs.

Comfort is that which is produced. The "demand" for this end-use product is useful in the analysis of energy conservation.

The following survey of this literature is an attempt to familiarize the reader with what has been done in this area up until the present. Many specific differences between the past literature and this dissertation will be

formally explained in the chapter that develops the theoretical model (Chapter III).

2.2. Theory of Household Production

A very important aspect of the consumption of comfort is that there is no market for its distribution. Consumers produce their own comfort by purchasing the necessary factors, i.e. air-conditioners, central heaters, insulation, energy, etc.

The body of theory that deals with the case of consumers producing their own commodities, household production, was initiated by Becker (1965). His main focus was on the implications of household production on the allocation of time between leisure and productive activity.

Becker's concept of household production dealt with activities that are much less concrete than the production of residential thermal comfort. He was interested in students' use of their time in the production process of education, in the use of parents' time in the production of high "quality children" and so forth.

Pollak and Wachter cited two main problems with this approach. One problem was the pervasiveness of joint production arising from time being a joint factor in the production of most commodities produced by the household. Allocating the joint cost amongst the different commodities is a major stumbling block in the accurate determination of commodity prices. However, in the household production of

comfort, the consumer's time is not a significant factor and the cost allocation problem is avoided.

The second problem cited by Pollak and Wachter dealt with the household's budget constraint. The normal case where households purchase their commodities at exogenous prices results in a linear budget constraint. But in the household production case, non-constant returns to scale technologies (non-linear production functions) result in non-linear budget constraints (non-constant marginal costs of production). Standard consumption theory always assumes exogenous commodity prices. Without this assumption Pollak and Wachter claim, it is impossible to distinguish a household's preferences from its technology when observing its consumption. This leads to an endogenous commodity price and thus confounds traditional consumption theory. Pollak and Wachter conclude that application of their model requires the household's technology to exhibit constant returns and no joint production.

Pollak (1978) analyzes the welfare evaluation aspects in the household production model. Pollak attempts to find a means of utilizing an expenditure function approach to get an exact welfare measure (i.e. compensating variation) and a cost-of-living index.

The expenditure function results from cost (expenditure) minimization subject to a utility level constraint. It is a function of commodity prices and a constant level of utility. Since expenditures are measured in dollars, the

change in the value of the expenditure function due to a change in a commodity price is an exact dollar measure of the welfare effect of that price change.

Of course, this welfare measure is predicated on the assumption of exogeneous commodity prices. Non-constant returns technologies lead to endogenous "implicit" commodity prices and therefore disrupt the use of the expenditure function. Thus, Pollak states that the use of the expenditure function for welfare evaluation is justifiable, "if and only if the technology exhibits constant returns to scale and no joint production."

Building upon the results of Pollak, Bockstael and McConnell (1983) restate the problems associated with household production and endogenous commodity prices. They deduce from Pollak and Wachter's edict on the proper use of the expenditure function that duality results do not hold in the household production framework. Without duality, Shephard's lemma and Roy's identity cannot be used to measure exact consumer's surplus (i.e., compensating variation and equivalent variation). Bockstael and McConnell conclude that the endogeneity of the implicit commodity prices precludes use of a "demand" function for household production in the measurement of welfare. They suggest the use of the demand for the factors of household production (i.e., time) to measure welfare changes.

It is a major conclusion from this dissertation that duality results <u>do</u> hold in the household production

framework. A full exposition of this claim is reserved for the next chapter.

2.3. Demand for Energy-Using Durables

As Bockstael and McConnell indicate, the demand for energy-using durables, a factor of household production, is a potential source of information by which to measure the welfare effect of utility-sponsored conservation programs. As noted in the introduction, there is a large body of engineering evidence that consumers under-invest in energy-using appliances for household thermal comfort. Indeed, this is a prime motivation for such conservation programs.

Whatever the reason, be it cost of information, uncertainty or something different, the apparent under-capitalization severely weakens the argument for using the demand for energy-using durables. A change in the quantity demanded of an energy-using durable in response to a public utility induced change in the price of the energy-using durable, accurately reflects a household's preferences only if we can assume the household possesses all the relevant information.

In spite of these apparent problems, there have been numerous studies of factor demand using the household production framework. A review of some of the more notable studies is provided below.

Hausman (1979) uses a qualitative-choice model to determine the demand for home air-conditioners. Although he

does not cite the household production literature, he discusses the interwoven nature of a household's technology and its preferences using the same terminology as Pollak and Wachter.

Hausman describes two models, a short-run model and a long-run model. In the short-run the quantity of energy-using durables is fixed, making the short-run cooling costs strictly operating costs. In the long-run however, a household can substitute between higher capital costs and lower operating costs by investing in more efficient energy-using durables.

The tradeoff between capital and operating costs is basically a tradeoff between present and future costs. From observations of this tradeoff, Hausman calculates the individual discount rate to be between 20 and 25 percent. He notes that this estimate "substantially exceeds values used in engineering calculations to determine so-called life-cycle costs for evaluating between . . . lower operating costs and higher initial capital costs." Hausman comments that "[e]nergy conservation through improved technology may have difficulty succeeding if consumers do have such a high discount rate." Hausman is essentially corroborating the engineering findings that households tend to under-invest in energy-efficient durables.

In her Ph.D. dissertation, Cameron (1982) applies the household production model using a sophisticated nested-logit estimation technique to analyze household retrofit

expenditures for space heating. Retrofit expenditures are defined as investments in higher efficiency space heaters, wall insulation, etc.

Cameron used the estimates of her model to simulate the costs and benefits of a subsidy on retrofit costs. A 50% subsidy of retrofit costs would induce only a 0.2% increase in retrofits, she concluded.

Cameron noted that it would be difficult to distinguish between those households that would be induced to install a retrofit by the subsidy and those households that would install a retrofit anyway. Under the "best-case" scenario, with only "induced" retrofitters claiming a subsidy and using a more realistic subsidy percentage of 15%, Cameron calculated the value of the energy saved to be approximately $204.4 million and the cost of the program to the government to be $160.3 million (in 1977-78 dollars). Under the "worst-case" scenario, where all retrofitters claim the subsidy, the benefits would be the same but the costs would balloon to $1.37 <u>billion</u>. If this were to occur, she claims, it would take approximately 6.7 years at a simple rate of return of 14.92% for society to recoup the costs of the program.

Along with the above stated general critique that these factor demand models assume households operate with a complete information set, Cameron can also be faulted for equating "energy costs saved" to "household benefits." Only if the demand for the commodity is perfectly inelastic is

the change in consumer's surplus, from a price reduction, equal to the reduction of costs of consumption.

The "worst-case" vs. "best-case" dilemma she cites is merely a question of transfers. She treats transfers from the government agency to consumers that would have invested in retrofits regardless of a subsidy as a deadweight loss. Clearly she understates the potential benefits of such a program. Also, like all the other studies, Cameron is forced to assume a linear cost of space-heating function in order to apply the standard consumption theory.

As stated in the introduction, another possible motivation for utility-sponsored conservation programs is the substitution of energy-using durables cost and energy-producing capacity costs. Parsons (1982) investigated this hypothesis using a reverse Avrch-Johnson model in conjunction with the household production model. A normal Avrch-Johnson model predicts a regulated utility will employ a more than optimal level of productive capital if the regulated rate of return is greater than the market-determined cost of capital. A reverse Avrch-Johnson model predicts a less than optimal level of capitalization if the regulated rate of return is <u>less</u> than the cost of capital.

Parsons claims, using data gathered from several California utilities, that the cost of capital has indeed risen above the regulated rate of return in the last decade. By subsidizing residential conservation investments, he

theorizes, utilities are "under-investing" in production capacity.

A major drawback to Parsons' conclusion is his categorization of the cost of subsidization as a non-capital expenditure. It is not clear, at least to this author, that by applying the cost of a conservation program to a utility's rate base, the utility has not simply substituted one kind of capital input for another. There may be real cost savings to be gained by this method which do not rely upon a reverse Aerch-Johnson model.

Mathur's (1984) theoretical paper applies the household production model to analyze government mandated building energy performance standards (BEPS). It is noteworthy that Mathur is the first and only energy economist to specifically cite the household production literature of Becker, Pollak and Wachter.

Mathur compares the efficiency of BEPS to government-sponsored pricing methods (taxation, price subsidization) in reducing the demand for energy. Not surprisingly, Mathur's theoretical model predicts BEPS are inherently less efficient than pricing policies.

Hartman (1984) applied the household production framework to the demand for water-heaters. His contribution to the model is the utilization of detailed technological information about different water heaters. Using data from Phoenix and Boston, which have very diverse climates, Hartman concluded that electric and gas utilities should

avoid direct subsidy programs, such as rebates and low interest-rate loans. These programs are simply not cost effective according to Hartman's estimation. He held out much more optimism for advertising/demonstration programs that sought to correct households' lack of information.

As with all of the studies, cost-effectiveness was used as a measure of welfare. The problems with this technique have already been stated. Hartman also assumes, without determining how crude an approximation it may be, a linear production function for heated water.

2.4. End-Use Demand

The above studies have used the household production framework to analyze the derived demand for the factor inputs of residential thermal comfort (i.e., electricity and capital). Another approach sometimes taken is to use the household production framework to analyze the demand for the produced commodity (i.e., comfort).

Two similar studies of this kind were performed by Scott (1980) and Capper and Scott (1981). Although no citations of the household production literature were made, Capper and Scott, in effect, apply the Pollak and Wachter model to the home heating case. As in the Pollak and Wachter theoretical paper (1975), Capper and Scott focus-in on the appropriate choice of a heating-space production function.

Their task was to define the shadow price of heated space as the cost of heated space divided by the quantity of heated space. This, of course, is simply the average cost of producing heated space. Consumption theory tells us that rational consumers make decisions on the margin. Unless the production function is linear in output, marginal cost will not equal average cost. That this distinction is lost on Capper and Scott is evidenced by the fact that they estimate both linear and log-linear cost functions.

Although this method used by others (Hartman, 1984, for example) is technically correct, it does rely on the linearity or near linearity of the production function. Ordinarily such assumptions are justified due to the lack of an alternative method. The model proposed in a later chapter of this dissertation will show that these assumptions are unnecessary.

Continuing the debate on the proper heated-space production function, Collins and Gray (1983) use Fourier's law of heat conduction to show that a house's R factor (a measurement of insulation level) is determined by the following equation.

$$R = \frac{ft^2 - h.(X-T)}{Btu} ,$$

where

ft^2 = square footage heated,

h = hours,

Btu = British thermal units,

and (X-T) = the difference between indoor and outdoor temperature.

By solving this equation for indoor temperature (X), Collins and Gray derive a heated-space production function that is linear in outdoor temperature (T) and insulation level (R). A major problem with this line of research is that models using such thoroughly sterile laws of nature might have poor predictive powers. For instance, the above function assumes perfectly efficient conversion of electricity (KWH) to heat (Btu) at all levels of output. Just how to modify such a model for a realistic application is unclear.

In a recent study Costello and Galen (1984) use the demand for thermal comfort concept to explicitly measure the welfare ramifications of utility-sponsored conservation programs in Illinois. They discuss the short-comings of cost-effectiveness studies usually conducted by engineers.

Costello and Galen point out that an investment that enhances the productive efficiency of a residence in effect lowers the price (marginal cost) of comfort (P_z). Like any other price decrease, there is a resulting increase in consumer's surplus, Costello and Galen's measurement of

economic welfare. Using Figure 2.1 to illustrate, the change in consumer surplus caused by a decrease of P_z from P_{z1} to P_{z2} is area A plus B. Z is the level of thermal comfort consumed.

Costello and Galen state that cost-effectiveness studies implicitly assume a perfectly inelastic demand for comfort. Thus, such studies underestimate the potential benefit to the consumer by the amount of area B.

Costello and Galen make two assumptions in the model for the sake of computational simplicity. Like all the other studies cited above, they assume an exogenous price (linear cost function). They assume a linear demand function as well.

With these simplifying assumptions, Costello and Galen can determine the areas A and B to be, respectively,

$$A = Z_1(P_{z1} - P_{z2})$$

and

$$B = (1/2)(Z_2 - Z_1)(P_{z1} - P_{z2}).$$

To convert these areas into what Costello and Galen consider more observable variables, they set

$$Z_i = F_i \cdot e_i$$

and

$$P_{zi} = P_f/e_i.$$

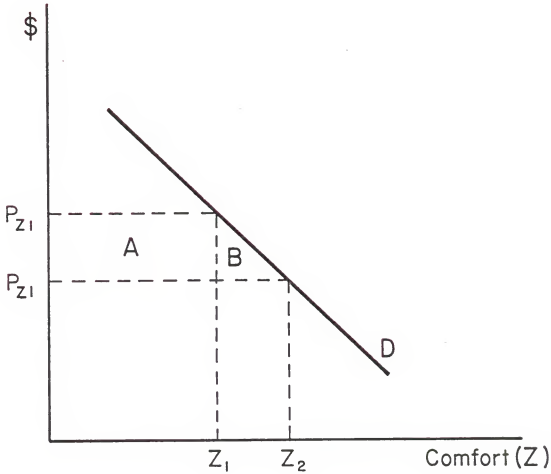

Figure 2.1.

Demand For Comfort Function.

F_i is the amount of fuel (electricity) required to produce Z_i. P_f is the price of fuel and e_i is a measurement of the productive efficiency of a given technology (furnace, air-conditioner, etc.). Conservation investments would supposedly increase the value of e_i and thus decrease P_{z1}. By substitution Costello and Galen derive that the change in consumer's surplus (ΔCS) resulting from a conservation program would be

$$\Delta CS = A + B = (\frac{3}{2})P_f F_1(1-\frac{e_1}{e_2}) + (\frac{1}{2})P_f F_2(1-\frac{e_2}{e_1}).$$

According to this formulation, one would only need know the ex-ante and ex-post expenditures on heating fuel and the relative values of e_1 and e_2, which are readily available using engineering studies. With the inclusion of the change in the utility's producer's surplus and the cost of the capital improvements, the data used by Costello and Galen suggest a positive net welfare gain from loan programs for wall insulation and window weatherization and a net welfare loss from rebate and loan programs for new high-efficiency furnaces. The net losses result from the gain in consumers' surplus being outweighed by the cost (to the consumer) of the capital improvement (i.e., new furnace). Noting that rational consumers would not willingly enter into such a program, Costello and Galen (1984, pg. 75) conclude that "a serious problem may exist with the data."

The problem may exist with the model itself. Besides the possible problems that may arise from erroneously assuming a constant marginal cost of producing comfort, since Costello and Galen use aggregated market data, they must assume that every consumer pays the same ex-ante and ex-post price. Clearly the price a consumer pays for comfort depends on climate and housing characteristics. Also it is not justified to assume all households start-out with the same relatively inefficient heating system and insulation level. In other words, each household produces its comfort level based on its own level of productive efficiency. Since every household is, in effect, paying a different price for comfort, use of a market demand function for welfare measurement can lead to serious miscalculations.

Another major drawback to this model is the assumption of linearity for every functional form. When accurate and dependable empirical results are desired, a more robust model, one that accommodates different functional forms, would inspire more confidence.

CHAPTER III

THEORETICAL FRAMEWORK OF THE MODEL

3.1. Introduction

The basis of this model, constrained utility maximization, is certainly not novel. What differentiates the household production models, of which this is one, from normal models is that the household does not purchase the utility maximizing combination of consumption good. It purchases the factors that produce the utility maximizing combination of consumption goods. What differentiates this model from the other household production models is that the production function that converts the factors into consumption goods is not assumed to exhibit constant returns to scale.

3.2. Constrained Utility Maximization and the Uncompensated Comfort Consumption Function

An obvious first step in contrained utility maximization is the definition of a utility function. A standard procedure is to define a function U( ) with only two arguments, Z and G:

$$U = U(Z,G) \quad . \tag{1}$$

U is assumed to be weakly separable, monotonically increasing and strictly concave in Z and G. Z is labeled "comfort," a term which can mean either heated space or cooled space. G is a composite good which includes all consumption goods other than comfort.

Certainly, heated space and cooled space are not the same thing. Yet, depending on the surrounding environment (i.e., cold weather or hot weather), the consumer derives similar satisfaction from both. Since it can be assumed that a rational consumer will never expend resources to increase and decrease his ambient room temperature simultaneously (i.e., operate an air-conditioner and a furnace at the same time), there need be only one argument in the representative utility function for comfort.

A natural unit of measurement for heating comfort would be degrees of temperature, either Fahrenheit or Celsius. Determining a unit of measurement for cooling comfort is a bit more complicated because it is clearly not monotonically increasing in temperature.

There are several possible methods of solving this problem. Perhaps the simplest is to denote the inverse of degrees of temperature as a cooling "index." Using this methodology we can define Z more precisely.

$$Z = Z(X) \quad , \tag{2}$$

where X = indoor ambient temperature.

To distinguish between heating and cooling comfort, we define T as outdoor temperature.

$$Z(X) = X \text{ when } X > T \text{ (i.e., in cool months)}$$

and

$$Z(X) = X^{-1} \text{ when } X < T \text{ (i.e., in warm months).}$$

The specification of comfort as the inverse of inside temperature may seem arbitrary. Indeed, its choice as the comfort index is for ease of calculation only. Other indices, such as 100 minus the inside temperature will be tried to determine the sensitivity of the estimated amounts to the choice of comfort index.

Models, such as this one, which attempt to establish a method of estimating the parameters of a household's utility function must make the necessary, albeit, theoretically implausible, assumption that all households have the same utility function. Hopefully, the mismeasurements of such an assumption are minimal if the degree of variation between different households' preferences is minimal.

There is a large body of literature on individuals' preferences for ambient room temperature. It was once believed that Eskimos actually preferred a lower ambient room temperature than persons from more temperate climates. This idea was advanced by Brown and Page (1952-1953). This study however was very unscientific. Numerous other studies have been devoted to determining how much people differ in

their preferences for ambient room temperature. The evidence is that individuals' room temperature preferences are largely invarient to age, occupation, climate, race, exercise level and gender (see Fanger, Hojbjerre and Thomsen, 1977; Winett, et al., 1982). Most of these studies indicate the preferred ambient room temperature to be approximately 75°F to 77°F. From this body of evidence, the assumption of identical utility functions across households may not present any serious misspecification.

Obviously, for constrained utility maximization, we need not only a utility function but also a budget constraint. Since comfort is produced at home and not purchased directly, we cannot simply multiply its price times its quantity to determine the budget constraint. Its cost function is what we need, and to determine its cost function, we must specify a production function.

The production functions for cooling and heating are respectively,

$$X = X^A(E^A, K^A, T) \text{ when } T > X \tag{3}$$

and

$$X = X^H(E^H, K^H, T) \text{ when } T < X \text{ ,} \tag{4}$$

where E^A = fuel input for cooling,

K^A = a vector of capital inputs for cooling,

E^H = fuel input for heating,

and K^H = a vector of capital inputs for heating.

It is assumed that X is monotonically increasing in E^H, K^H and T and monotonically decreasing in E^A and K^A. Examples of E^A and E^H are electricity, coal, oil, gas, etc. Examples of K^A and K^H are air-conditioners, heat pumps, insulation, etc. Electricity-using appliances like air-conditioners are measured by capacity and efficiency rating. For notational simplicity, I will use the symbols E and K to represent fuel and capital levels for both heating and cooling.

The next step is to determine the cost function. In order to do this, we must remember there are two kinds of cost functions (long-run and short-run) and, therefore, there are two kinds of budget constraints.

In the short-run, all capital inputs are assumed fixed. Only the level of fuel input can be adjusted to alter the level of comfort produced. This in effect makes the cost of comfort equal to the expenditures on fuel input. Thus, the short-run cost function for comfort is a function of the price of the fuel input P^E, K, T and Z.

$$P^E E = C^S(P^E, K, T, Z) \quad , \tag{5}$$

where $C^S(P^E, K, T, Z)$ is referred to as the short-run cost of comfort function. A subscript for the cost function indicates a partial derivative. The signs of the partial derivatives are assumed to be $C^S_K < 0$, $C^S_Z > 0$, $C^S_{KZ} < 0$ and $C^S_{KK} > 0$ (the regularity assumptions).

In the long-run all inputs are variable. If the producer is a cost-minimizer, then he will employ the combination of inputs such that the ratio of their marginal products (the marginal rate of substitution) is equal to the ratio of their prices (the slope of the iso-quant). Thus, the long-run cost function for comfort is a function of the prices of all the inputs (P^E and P^K) and T and Z.

$$P^K K + P^E E = C^L(P^E, P^K, T, Z) \quad , \tag{6}$$

where $C^L(P^E, P^K, T, Z)$ is referred to as the long-run cost of comfort function. The price of capital is actually an imputed discount-rate.

These two cost functions are used to determine the long and short-run budget constraints which are respectively,

$$Y = C^L(P^E, P^K, T, Z) + G \tag{7}$$

and

$$U = C^S(P^E, K, T, Z) + G \ . \tag{8}$$

Y is disposable income and G is the amount of income devoted to consumption of all goods other than comfort. The price of one unit of G is set at $1.

It is easy to distinguish the only difference between the long-run and short-run functions. The former is a function of the price of capital, whereas the latter is a function of the level of capital.

Since the data used in this dissertation, to be discussed in detail in the next chapter, lend themselves to the short-run case, I will only consider the short-run budget constraint in order to eliminate unnecessary redundancy. The following methodology is essentially the same for either the long-run or the short-run. The superscript "S" will be suppressed.

We now can maximize utility subject to our budget constraint using a Lagrangian multiplier.

$$L = U(Z,G) + \lambda(Y-C(P^E,K,T,Z)-G) \ . \tag{9}$$

The first-order conditions are

$$L_Z = U_Z - \lambda C_Z = 0 \tag{10}$$

and

$$L_G = U_G - \lambda = 0 \ . \tag{11}$$

U_Z and U_G are the partial derivatives of the utility function with respect to Z and G respectively. C_Z is the marginal cost of comfort.

By dividing equation (10) by equation (11), we get the maximization condition

$$\frac{U_Z}{U_G} = C_Z \ . \tag{12}$$

This condition states that at maximum utility, the marginal rate of substitution (the ratio of the marginal utilities) is equal to the marginal rate of transformation (the ratio of the marginal costs). Remember that the marginal cost of consuming one unit of G is its price, $1.

By substituting the budget constraint (8) into (12) and solving for Z, we get

$$Z = F(P^E, K, T, Y) \quad . \tag{13}$$

This equation is referred to as the (short-run) uncompensated comfort consumption function (UCC).

To better understand the relevance of this function, it is helpful to think of the marginal cost of comfort as the "shadow price" of consuming comfort. If the cost function were linear in Z, then the marginal cost of Z would be constant, just like an exogenous price. In this case, equation (12) is simply the (inverse) Marshallian or uncompensated demand function for comfort. Hence, the name <u>uncompensated</u> comfort consumption function.

That (13) is not a demand function results from the (possibly) non-linear cost function. The "shadow price" of comfort may vary with the level of consumption, thus violating the price exogeneity assumption. All the previous studies on energy conservation which use the household production framework assume a linear cost function.

As Pollak and Wachter proved, without a constant returns to scale technology, standard welfare measures from demand equations are not valid. For illustration, refer to Figure 3.1. An increase in K (not purchased with income) will increase the horizontal intercept of the production possibilities frontier since the marginal product of K is always positive. The slope of the PPF (the marginal rate of transformation) is decreased along with the marginal cost of comfort. The new equilibrium is at a higher level of utility (a higher indifference curve) and at a higher level of comfort consumption. The relationship between the level of K and Z is the UCC function. It is upward sloping since the marginal product of K and the marginal utility of Z are always positive. I am assuming of course that comfort is a normal good.

Unlike the Marshallian demand function, no welfare measures can be derived from the UCC function alone. Both functions identify the locus of points where the marginal cost of consumption equals the marginal utility (or marginal benefit) of consumption. But whereas a demand function, a function of price, can give dollar-valued measurements of welfare (consumer's surplus), the UCC function is a function of K which is not measured in dollars. Therefore, the UCC function does not render a dollar-valued welfare measure. But as will be demonstrated in the following section, the UCC function <u>can</u> be used in conjunction with the marginal

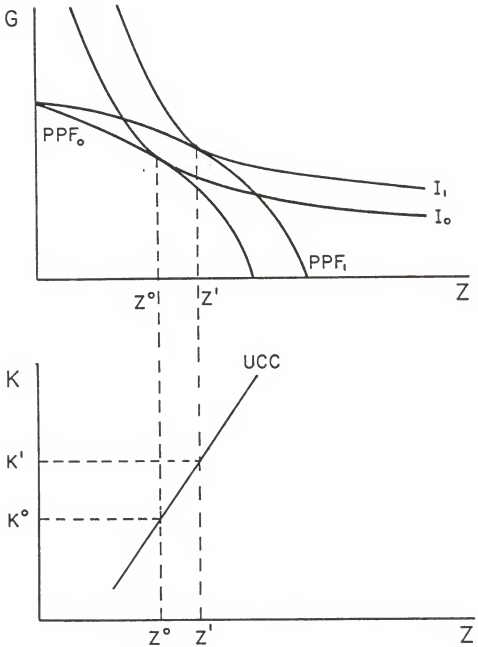

Figure 3.1.

Derivation of the Uncompensated Comfort Consumption Function.

cost function to derive an uncompensated dollar-valued measure of welfare.

3.3. Marginal Cost and The Uncompensated Marginal Benefit of Comfort Function

A Marshallian demand function gives us a welfare measure of consumption because it can be thought of as a marginal benefit of consumption function (if we ignore income effects). Since all utility maximizing consumers purchase the quantity where price (the marginal cost of consumption) equals the marginal benefit of consumption, variations in price "trace-out" an uncompensated marginal benefit function (the uncompensated demand function).

In the household production case, the UCC function plots-out the combinations of K and Z where utility is maximized (marginal cost equals marginal benefit). Variations in K cause variations in the marginal cost of comfort, which "trace-out" an uncompensated marginal benefit of comfort function (UMB), which is analogous to the Marshallian demand function.

This "tracing-out" is achieved by inverting the UCC function to solve for K,

$$K = F^{-1}(P^E, Z, T, Y) \tag{14}$$

and substituting this into the marginal cost function, C_Z. The result is

$$C_Z(P^E, F^{-1}(P^E, Z, T, Y), T, Z) = B_Z(P^E, Z, T, Y) \quad . \qquad (15)$$

$B(P^E, Z, T, Y)$ is the (uncompensated) benefit function and B_Z is the (uncompensated) marginal benefit function.

To graphically illustrate this process, Figure 3.2 is provided. By increasing the level of capital input, the UCC function indicates the resultant increase in the level of comfort consumed. This increase in K lowers the marginal cost of comfort at all levels of comfort. The changes in K and marginal cost "trace-out" the UMB.

For normal linear systems, the short-run demand function is less elastic than the long-run demand function. Such a comparison would be difficult in the present case however. Due to the nonlinear contraint, the concept of elasticity, as it is normally defined, does not apply here. Therefore, we will sidestep the issue of the relative elasticities between the long-run and short-run UMB functions.

The benefit to the consumer of the exogenous increase in K is the shaded area between the ex-ante and ex-post marginal cost curves and the UMB. Since the UMB is analogous to the Marshallian demand function, we will refer to this welfare measure as the change in consumer's surplus (ΔCS).

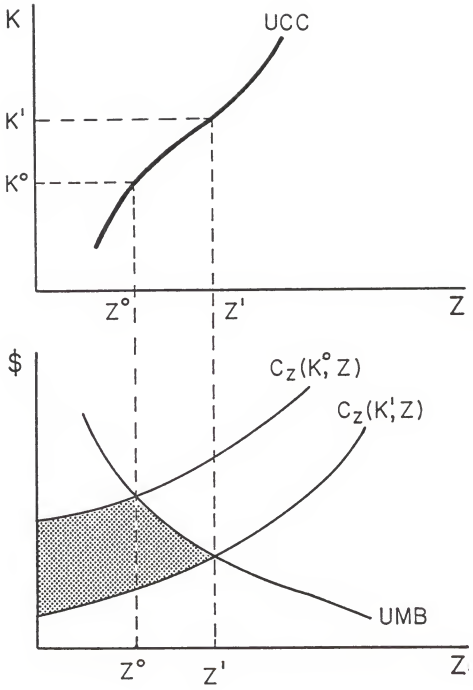

Figure 3.2.

The Uncompensated Marginal Benefit Function.

Mathematically, this area is

$$\Delta CS = \int_0^{Z^0} (C_Z(K^0,Z) - C_Z(K^1,Z))dZ + \int_{Z^0}^{Z^1} (B_Z(Z) - C_Z(K^1,Z))dZ$$

$$= C(K^0,Z^0) - C(K^1,Z^0) + B(Z^1) - B(Z^0) - C(K^1,Z^1) + C(K^1,Z^0) \ . \qquad (16)$$

Z^0 and Z^1 are the pre- and post-investment levels of comfort consumed respectively, and K^0 and K^1 are the ex-ante and ex-post levels of capital investment. Since the arguments P^E, T and Y do not vary, they have been suppressed in the cost and benefit functions.

Equation (16) simplifies to

$$\Delta CS = C(K^0,Z^0) - C(K^1,Z^1) + B(Z^1) - B(Z^0) \ . \qquad (17)$$

The first two terms in (17) sum to be the change in fuel costs caused by the infusion of K. The last two terms sum to be the dollar-valued benefit of the increase in comfort. Graphically, this is the area under the UMB bounded by Z^0 and Z^1 (see Figure 3.3).

Bockstael and McConnell (1983) mention, in a short paragraph, the above method of "tracing-out" a Marshallian demand function (their name for my UMB) as theoretically possible. But Bockstael and McConnell quickly dismiss this method since they claim it requires knowledge of the marginal cost of production at all levels of output. From

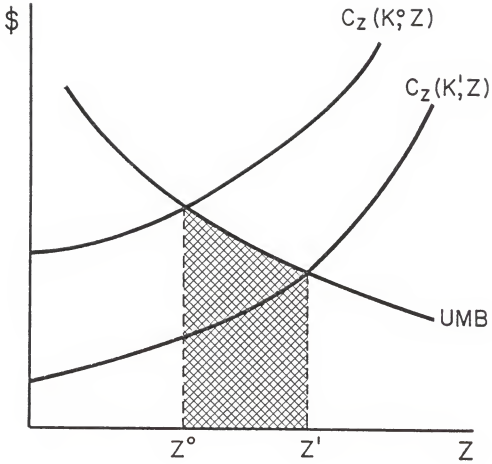

Figure 3.3.

Benefit of Increase in Comfort.

equation (17), we see that this is simply not so. All that is required is knowledge of the marginal cost of production at the levels consumed and knowledge of the change in total cost. Certainly this method is not as difficult to utilize as Bockstael and McConnell assume.

To measure the net welfare gain of the increase in K, one must subtract the discounted cost of the increased investment from the gain in consumer's surplus. If consumers produce comfort using the least cost technology, then any such program that alters the combination of K and Z must have negative welfare effects. The discounted increased cost of K would be greater than the gain in consumers' surplus. If, as was previously stated, consumers are not using the least-cost technology, then there may be a positive welfare gain. The measurement of the welfare gain or loss is a possible test of the hypothesis that consumers are undercapitalizing.

3.4. The Income Compensated Consumption Function

As the name implies, the uncompensated comfort consumption function assumes the nominal income of the household is fixed and ignores any real income effects that the change in K might have. In order to measure the exact change in welfare from a price change, the level of utility and hence the real income level must remain unchanged. Therefore, for instance, a reduction in the price which increases real income must be compensated by a reduction in nominal income.

Demand functions which maintain a constant level of utility (as price changes) are called Hicksian or compensated demand functions. They are derived by differentiating the expenditure function with respect to the price that changes. This is Shephard's lemma applied to consumption theory.

Since there are two real income or utility levels, the ex-ante and ex-post levels, there are two compensated demand functions and two different welfare measures that can be derived from them. The area bounded by the ex-ante and ex-post prices and the compensated demand function using the ex-ante level of utility is called the compensating variation (CV). The area bounded by the ex-ante and ending prices and the compensated demand function using the ex-post level of utility is called the equivalent variation (EV).

Willig (1976) has shown that

$$CV \leq \Delta CS \leq EV$$

for any price decrease. Under certain conditions, such as small price changes and small income elasticities, ΔCS is a reasonably close approximation to the theoretically more exact measures CV and EV. Willig's work has been cited frequently in justification of the use of the ΔCS.

Hausman (1981) showed however that the use of an uncompensated measure can be a very bad approximation when measuring deadweight losses. Hausman's solution was to use

Roy's identify which relates the (observable) Marshallian demand function to the (unobservable) Hicksian demand function. This technique is only a little more involved than using the ΔCS.

A utility sponsored conservation program which attempts to induce the household to employ a more efficient combination of inputs is actually attempting to reduce the deadweight loss of undercapitalization. Since the reduction in deadweight loss is the gain in net welfare of such programs, the exclusive use of an uncompensated measure might present serious mismeasurements of the performance of these conservation programs.

In order to derive these exact measures of welfare, we must first establish an indirect utility function for the household production case. In the normal case, where all commodities are purchased at exogenous prices, the indirect utility function is derived by substituting into the utility function the Marshallian demand functions for the arguments of the utility function.

Analogously, for the household production case, we substitute the UCC function and the Marshallian demand function for $G, D(P^E, K, T, Y)$, into the utility function

$$U(F(P^E, K, T, Y),\ D(P^E, K, T, Y)) = v(P^E, K, T, Y)\ . \tag{18}$$

$v(P^E, K, T, Y)$ is the indirect utility function in the household production case.

Next we derive the expenditure function by inverting the indirect utility function to solve for income.

$$Y = v^{-1}(P^E,K,T,U) = e(P^E,K,T,U) \quad . \tag{19}$$

$e(P^E,K,T,U)$ is the expenditure function for the household production case.

The normal procedure, when prices are exogenous, is to apply Shephard's lemma to derive the income compensated demand function. But as Pollak and Wachter have concluded, Shephard's lemma applied in its usual form does not render a compensated demand function (or compensated comfort consumption function) unless the production function exhibits constant returns to scale.

The solution therefore is a modified Shephard's lemma.

Shephard's lemma, for the household production case:

$$f(P^E,K,T,U) = C_K^{-1}(P^E,K,T,e_K(P^E,K,T,U)) \quad . \tag{20}$$

C_K^{-1} is the inverted partial derivative of the cost function with respect to K solved for Z. e_K is the partial derivative of the expenditure function with respect to K. $f(P^E,K,T,U)$ is the (income) compensated comfort consumption function (CCC).

Proof:

Let us define a function,

$$g(K) = e(P^E,K,T,U) - C(P^E K,T,Z^*) - G^* , \tag{21}$$

where Z^* and G^* are the expenditure minimizing amounts of Z and G that produce U level of utility when $K = K^*$. Since $e(P^E,K,T,U)$ is the cheapest way to get U, $g(K)$ is always nonpositive. At $K = K^*$, $G(K^*) = 0$. Since this is a maximum value of $g(K)$, its derivative must be zero,

$$g_K(K^*) = e_K(P^E,K^*,T,U) - C_K(P^E,K^*,T,Z^*) = 0 . \tag{22}$$

Thus the derivative of e is not equal to the Hicksian quantity demanded (as in the exogenous price case), but the derivative of the cost function

$$e_K(P^E,K^*,T,U) = C_K(P^E,K^*,T,Z^*) . \tag{23}$$

To derive the CCC function, we invert C_K and solve for Z,

$$Z = C_K^{-1}(P^E,K,T,e_K(P^E,K,T,U)) = f(P^E,K,T,U) . \tag{24}$$

Q. E. D.

3.5 Marginal Cost and The Income Compensated Marginal Benefit of Comfort

Now that we have a compensated comfort consumption function, a compensated marginal benefit of comfort function (CMB) must be derived. Using the same method used to derive the UMB function, we invert the CCC function to solve for K,

$$K = f^{-1}(P^E, Z, T, U) \quad . \tag{25}$$

We substitute equation (25) into the marginal cost function to get the CMB,

$$C_Z(P^E, f^{-1}(P^E, Z, T, U), T, Z) = b_Z(P^E, Z, T, U) \quad . \tag{26}$$

$b(P^E, Z, T, U)$ is the income compensated benefit function and $b_Z(P^E, Z, T, U)$ is the income compensated marginal benefit function.

For a graphical illustration, see Figures 3.4 and 3.5. Using the ex-ante level of U, U^0, we see that by eliminating the income effect, Z^1 is reduced to Z_0^1. The CCC function at level U^0, $f(P^E, K, T, U^0)$, is thus steeper (more positively sloped) than the UCC function, and the resulting CMB at utility level U^0, $b_Z(P^E, Z, T, U^0)$, is steeper (more negatively sloped) than the UMB. Likewise, using the ex-post level of U, U^1, we see that Z^0 is increased to Z_1^0. The CCC function at level U^1, $f(P^E, K, T, U^1)$, is steeper than the UCC function and the CMB at level U^1, $b_Z(P^E, Z, T, U^1)$, is steeper than the UMB.

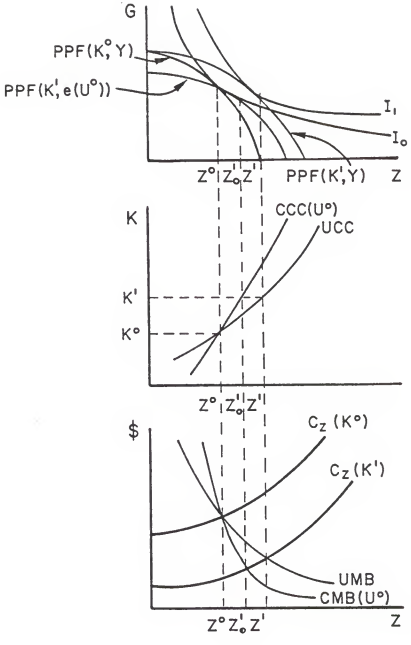

Figure 3.4.

Ex-Ante Compensated Marginal Benefit Function.

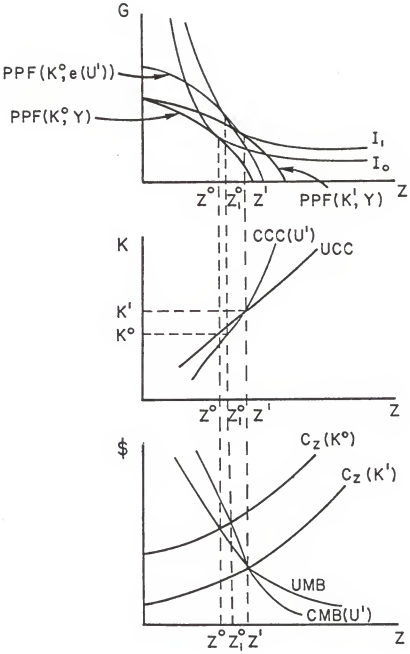

Figure 3.5.

Ex-Post Compensated Marginal Benefit Function.

As in the exogenous price case, there are two measures of exact consumer's surplus (see Figures 3.6 and 3.7). The compensating variation (CV) is the area between the ex-ante and ex-post marginal cost curves and the CMB when $U = U^0$. The equivalent variation (EV) is the area between the ex-ante and ex-post marginal cost curves and the CMB when $U = U^1$.

Mathematically, these statements are

$$CV = \int_0^{Z^0} (C_Z(K^0,Z) - C_Z(K^1,Z))dZ + \int_{Z^0}^{Z_0^1} (b_Z(Z,U^0) - C_Z(K^1,Z))dZ \tag{27}$$

and

$$EV = \int_0^{Z_1^0} (C_Z(K^0,Z) - C_Z(K^1,Z))dZ + \int_{Z_1^0}^{Z^1} (b_Z(Z,U^1) - C_Z(K^1,Z))dZ \ . \tag{28}$$

Like equation (16), (27) and (28) simplify to

$$CV = C(K^0,Z^0) - C(K,Z_0^1) + b(Z_0^1,U^0) - b(Z^0,U^0) \tag{29}$$

and

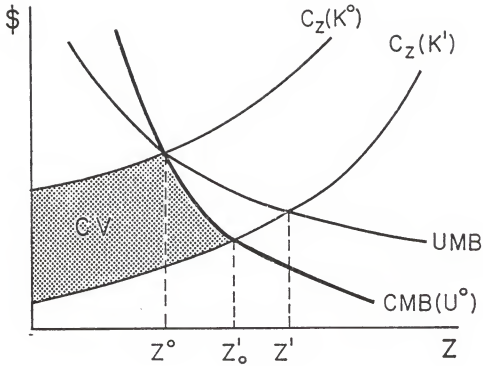

Figure 3.6.

Compensating Variation.

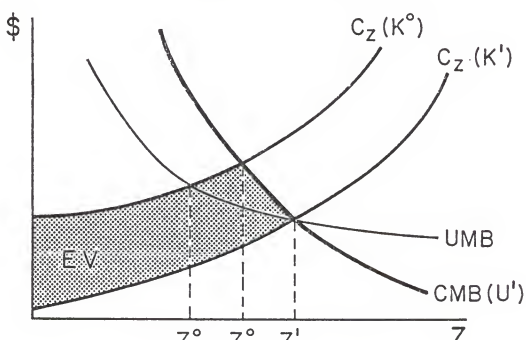

Figure 3.7.

Equivalent Variation.

$$EV = C(K^0, Z_1^0) - C(K^1, Z^1) + b(Z^1, U^1) - b(Z_1^0, U^1) \quad . \qquad (30)$$

In the exogenous price case, there are two main results. As was stated earlier, $CV \leq \Delta CS \leq EV$. Also, CV is the change in the value of the expenditure function holding $U = U^0$. EV is the change in the value of the expenditure function holding $U = U^1$.

The first result, used by Willig to show that ΔCS is a good approximation of CV and EV, is easy to verify (in the exogenous price case), since the elimination of the income effect (for a normal good) makes the compensated demand function steeper than the uncompensated demand function. The area, bounded by the ex-ante and ex-post prices, under the compensated demand function holding $U = U^0$, CV, must be less than the area bounded by the prices under the uncompensated demand function, ΔCS. Likewise, the area bounded by the prices under the compensated demand function holding $U = U^1$, EV, must be greater than ΔCS.

The second statement follows directly from Shephard's lemma. If the compensated demand function holding $U = U^0$ is the derivative of the expenditure function, then the integral of the compensated demand function from the beginning price to the ending price (CV) is equal to the change in the expenditure function. The same argument holds for EV.

The veracity of these statements for the household production case is less straightforward. A useful tool, for

this purpose, is a rule of integration for inverted functions.

Rule of Integration for Functions of Inverted Functions:

$$L - (p^i,q^i) - h(p^j,q^j) = \int_{p^j}^{p^i} h_p(p,q(p))dp + \int_{q^i}^{q^j} h_q(p(q),q)dq \ , \tag{31}$$

for functions $h(p,q)$, $p = p(q)$, $q = q(p)$, where $p(q)$ is the inverse function of $q(p)$ ($p^{-1}(q) = q(p)$ and $q^{-1}(p) - p(q)$). $i \neq j$.

<u>Proof</u>:

Take the total differential of h,

$$dh = h_p(p,q)dp + h_q(p,q)dq \ . \tag{32}$$

Since p and q are inverses of each other, we see that

$$dh = h_p(p,q(p))dp + h_q(p,q(p))dq \ . \tag{33}$$

Taking the total differential of $q(p)$, we get

$$dq = q_p(p)dp \ , \tag{34}$$

therefore

$$dh = h_p(p,q(p))dp + h_q(p,q(p))q_p(p)dp \tag{35}$$

and

$$\frac{dh}{dp} = h_p(p,q(p)) + h_q(p,q(p))q_p(p) \ . \tag{36}$$

By integrating both sides, we see that

$$h(p,q) = \int h_p(p,q(p))dp + \int h_q(p,q(p))q_p(p)dp + R \ , \tag{37}$$

where R is a constant of integration. Using equation (34) to change the variable of integration and applying the fundamental theorem of calculus, we get

$$h(p^i,q^i) - h(p^j,q^j) = \int_{p^j}^{p^i} h_p(p,q(p))dp + \int_{q^j}^{q^i} h_q(p(q),q)dq \tag{38}$$

Q. E. D.

We can use this rule of integration to prove that $CV \leq \Delta CS \leq EV$, for the household production case.

Proof:

From equations (17) and (29), we see that

$$\begin{aligned}\Delta CS - CV &= C(K^0,Z^0) - C(k^1,Z^1) + B(Z^1,Y) - B(Z^0,Y) - \\ &\quad C(K^0,Z^0) + C(K^1,Z_0^1) - b(Z_0^1,U^0) + b(Z^0,U^0) \\ &= C(K^1,Z_0^1) - C(K^1,Z^1) + B(Z^1,Y) - B(Z^0,Y) \\ &\quad + b(Z^0,U^0) - b(Z_0^1,U^0) \ . \end{aligned} \tag{39}$$

From the fundamental theorem of calculus,

$$B(Z^1,Y) - B(Z^0,Y) = \int_{Z^0}^{Z^1} B_Z(Z,Y)dZ \tag{40}$$

and

$$b(Z^0,U^0) - b(Z_0^1,U^0) = \int_{Z_0^1}^{Z^0} b_Z(z,U^0)dZ \ . \tag{41}$$

From these two equations and equations (15) and (26), we see that

$$B(Z^1,Y) - B(Z^0,Y) = \int_{Z^0}^{Z^1} C_Z(F^{-1}(Z,Y),Z)dZ \tag{42}$$

and

$$b(Z^0,U^0) - b(Z_0^1,U^0) = \int_{Z_0^1}^{Z^0} C_Z(f^{-1}(Z,U^0),Z)dZ \ . \qquad (43)$$

From equations (13), (14), (20) and (25), we know that

$$Z^i = F(K^1,Y) \ ,$$

$$K^i = F^{-1}(Z^i,Y) \ ,$$

$$Z_j^i = f(K^i,U^j) \ ,$$

and

$$K^i = f^{-1}(Z_j^i,U^j) \ .$$

Therefore from our rule of integration,

$$\int_{Z^j}^{Z^i} C_Z(F^{-1}(Z,Y),Z)dZ = C(K^i,Z^i) - C(K^j,Z^j) - \int_{K^j}^{K^i} C_K(K,F(K,Y))dK \qquad (44)$$

and

$$\int_{Z^j}^{Z_j^i} C_Z(f^{-1}(Z,U^j),Z)dZ = C(K^i,Z^i) - C(K^j,Z_j^i) + \int_{K^j}^{K^i} C_K(K,f(K,U^j))dK \ , \qquad (45)$$

where $i \neq j$.

From equations (42)-(45), we see that

$$B(Z^1,Y) - B(Z^0,Y) = C(K^1,Z^1) - C(K^0,Z^0) - \int_{K^0}^{K^1} C_K(K,F(K,Y))dK \tag{46}$$

and

$$b(Z^0,U^0) - b(Z^1,U^0) = C(K^0,Z^0) - C(K^1,Z^1) + \int_{K^0}^{K^1} C_K(K,f(K,U\ ))dK\ . \tag{47}$$

Substituting (46) and (47) into (39) and simplifying results in

$$\Delta CS - CV = \int_{K^0}^{K^1} (C_K(K,f(K,U^0)) - C_K(K,F(K,Y)))dk\ . \tag{48}$$

Again, envoking the fundamental theorem of calculus, we see that

$$C_K(K,f(K,U^0)) - C_K(K,F(K,Y)) = \int_{f(K,U^0)}^{F(K,Y)} C_{KZ}(K,Z)dZ \tag{49}$$

Substituting (49) into (48), we get

$$\Delta CS - CV = - \int_{K^0}^{K^1} \int_{f(K,U^0)}^{F(K,Y)} C_{KZ}(K,Z)\,dZdK \ . \qquad (50)$$

From our regularity condition

$$C_{KZ}(K,Z) < 0 \ ,$$

and since $K^0 < K^1$ and $f(K,Y) \geq f(K,U^0)$, for all $K^0 \leq K \leq K^1$, we know that (50) is non-negative, therefore $CV \leq \Delta CS$, Using a similar process, we see that

$$EV - \Delta CV = - \int_{K^0}^{K^1} \int_{F(h,Y)}^{f(K,U^1)} C_{KZ}(K,Z)\,dZdK \ . \qquad (51)$$

Since, $f(K,U^1) \geq F(K,Y)$, for all $K^0 \leq K \leq K^1$, we see that (51) is also non-negative. Therefore $CV \leq \Delta CS \leq EV$, for the household production case.

Q. E. D.

The rule of integration for functions of inverted functions can also be used to prove that

$$CV = e(K^0,U^0) - e(K^1,U^0) \qquad (52)$$

and

$$EV = e(K^0,U^1) - e(K^1,U^1) \ . \qquad (53)$$

Proof:

From (29) and (30), we know

$$CV = C(K^0,Z^0) - C(K^1,Z_0^1) + b(Z_0^1,U^0) - b(Z^0,U^0)$$

and

$$EV = C(K^0,Z_1^0) - C(K^1,Z^1) + b(Z^1,U^1) - b(Z_1^0,U^1) \ .$$

From (26) and the fundamental theorem of calculus,

$$b(Z_0^1,U^0) - b(Z^0,U^0) = \int_{Z^0}^{Z_0^1} C_Z(f^{-1}(Z,U^0),Z)dZ \tag{54}$$

and

$$b(Z^1,U^1) - b(Z_1^0,U^1) = \int_{Z_1^0}^{Z^1} C_Z(f^{-1}(Z,U^1),Z)dt \ . \tag{55}$$

From our rule of integration,

$$C(K^0,Z^0) - C(K^1,Z_0^1) = \int_{K^1}^{K^0} C_K(K,f(K,U^0))dK + \int_{Z_0^1}^{Z^0} C_Z(f^{-1}(Z,U^0),Z)dZ \tag{56}$$

and

$$C(K^0,Z^0) - C(K^1,Z^1) = \int_{K^1}^{K^0} C_K(K,f(k,U^1))dK + \int_{Z^1}^{Z_1^0} C_Z(f^{-1}(Z,U^1),Z)dZ \tag{57}$$

Substituting (54) and (56) into (29), and (55) and (57) into (30), we get

$$CV = \int_{K^1}^{K^0} C_K(K,f(K,U^0))dK \tag{58}$$

and

$$EV = \int_{K^1}^{K^0} C_K(K,f(K,U^1))dK \tag{59}$$

From our Shephard's lemma for the household production case (equation (23)), we know

$$e_K(K,U) = C_K(K,Z) \ .$$

Substituting into (58) and (59), we get

$$CV = \int_{K^1}^{K^0} e_K(K,U^0)dK \tag{60}$$

and

$$EV = \int_{K^1}^{K^0} e_K(K,U^1)\,dK \tag{61}$$

and from the fundamental theorem of calculus,

$$CV = e(K^0,U^0) - e(K^1,U^0)$$

and

$$EV = e(K^0,U^1) - e(K^1,U^1) \ .$$

Q. E. D.

3.5. Observation of the Compensated Comfort Consumption Function

The prime motivating consideration for using the ΔCS was that compensated demand functions were unobservable. Therefore the ΔCS was better than nothing and according to Willig, was in all likelihood a close approximation of CV and EV.

However, Roy's identity, which relates the uncompensated demand function to the indirect utility function, allows us to "observe" the uncompensated demand function. As proposed by Hausman, since the uncompensated demand is equal to the negative of the ratio of the partial derivatives of the indirect utility function (the partial derivative of v with respect to price divided by the partial derivative with respect to income), we can solve the partial derivative equation for v. By inverting v, we get the expenditure function, which is used to calculate CV and EV.

Thus by observing the uncompensated demand function, we can estimate CV and EV.

Hausman (1981) derived the resulting expenditure function from a linear uncompensated demand function. Since the uncompensated demand function is invariant to monotonic transformations of the (indirect) utility function, when an economist chooses a functional form for the uncompensated demand function (such as a linear one), he is implicitly choosing a family of functional forms for the utility function. By estimating the parameters of an uncompensated demand function, he is simultaneously estimating the parameters of the utility function and thus the expenditure function. As long as personal income observations are available, the derivation of the expenditure function from the uncompensated demand function is very straightforward.

Bockstael and McConnell (1983, pg. 808) state "the utility and expenditure functions exist [in the household production case], but the absence of prices [constant marginal costs] prevents the use of Roy's identity to derive the Marshallian curve from the indirect utility function." With the help of our modified Shephard's lemma, we shall see that this statement is not correct.

Roy's identity, for the household production case is

$$F(K,Y) = C_K^{-1}(K, \frac{-v_K}{v_Y}) \ , \tag{62}$$

where V_K and V_Y are the partial derivatives of the indirect utility function with respect to K and Y respectively.

Proof:

Suppose that Z* and G* maximize utility at (K*,Y*). This means that Z* = F(K*, Y*) and G* = D(K*,Y*). Let U* = U(Z*,G*) = U(F(K*,Y*), D(K*,Y*)) = v(K*,Y*). It is also true that U* = v(K,e(K,U*)). Since U* is the maximal utility, we can differentiate it to get

$$0 = V_K(K,Y^*) + v_Y(K^*,Y^*)e_K(K,U^*) \tag{63}$$

or

$$e_K(K,U^*) = \frac{-v_K}{V_Y} . \tag{64}$$

From our modified Shephard's lemma, we see that

$$e_K(K^*,U) = C_K(K^*,f(K,U^*)) . \tag{65}$$

Since at maximum utility

$$f(K,U^*) = F(K,Y) , \tag{66}$$

we see that

$$C_K(K,F(K,Y)) = \frac{-v_K}{v_Y} . \tag{67}$$

By inverting C_K, we see that

$$F(K,Y) = C_K^{-1}(K, \frac{-v_K}{v_Y}) \quad . \tag{68}$$

Q. E. D.

We now have the theoretical model that allows us to make our welfare evaluations. A non-linear budget constraint renders the "shadow price" endogenous to the level of consumption. It therefore is not a reduced form equation and cannot be econometrically estimated. But the CCC function and the cost function <u>are</u> reduced form equations and can be used to make our welfare evaluations.

CHAPTER IV

DATA

4.1. Introduction

This chapter describes the data set used to estimate the model described in Chapter III. After describing the method used in gathering the data, the various adjustments to the observations are explained.

4.2. Electricity Consumption Data

Beginning in 1982, Florida Power and Light Company (FPL), the main electrical utility for southern and eastern Florida, conducted an experiment to determine consumer responses to energy conservation measures furnished by an electric utility. This experiment was titled the Residential Energy Conservation Demonstration project (RECD).

The main goal of the RECD project was to determine the cost effectiveness and customer response of the implementation of three different conservation enhancements: increased ceiling insulation, high efficiency central air-conditioning units and heat pumps. The experimental design was to select a large group of FPL customers and divide this group into two sub-categories. These categories were (a) a control group which received no conservation

enhancements but did have its energy consumption (by the central heating, ventilating and air-conditioning (HVAC) system) monitored and (2) a group of customers that did receive conservation enhancements and had their HVAC energy consumption monitored.

To be eligible to participate, the customer had to be an owner-occupant of a centrally heated and cooled, detached single-family dwelling. Out of 1,046,312 eligible households, 15,002 were randomly selected to answer a one-page, bilingual (English/Spanish) questionnaire. From the eighty percent who answered the questionnaire, 505 customers were selected to participate in the experiment. The participants were separated into six different groups:

Table 4.1. Breakdown of Participants

Description	Number of Participants
1. Control Group	217
2. Received Insulation Only	144
3. Received A/C Only	18
4. Received A/C and Insulation	54
5. Received Heat Pump Only	19
6. Received Heat Pump and Insulation	53
	505

The amount of insulation received depended on the participants' previous insulation level. Those with R-values of ten or less received R-19, equivalent to six inches of fiberglass. Those with R-values ranging from eleven to eighteen received R-11. Thus all recipients of insulation ended up with at least R-19 of insulation.

The air conditioner installed had energy efficiency ratios (EER) of 10 or slightly greater. The heat pumps installed had EERs of 8 or better. An EER is the heat (in BTUs) that a properly sized unit can remove from a house per watt of electrical energy input at design conditions.

The efficiency rating of a heat pump's heating ability (heat pumps both cool and heat houses) is the coefficient of performance (COP). The COPs for the installed heat pumps were 2.5 and greater. The COP is calculated as the amount of heat output (in BTUs per hour) divided by the amount of heat input. Thus the COP of standard resistance heating is always 1. The nameplate COP of a heat pump is calculated at design conditions and declines with outdoor temperature due to the compressor operating less efficiently. It shuts down completely at very cold temperatures.

In the preliminary interviews, the participants were queried regarding their thermostat settings and income levels. Also measured were the square footage of the residences and other socioeconomic variables, such as number of children at school age, etc.

The electricity consumption (of the HVAC systems) was recorded by meters which were read approximately every 30 days (a billing month). The billing months observed were October 1982 through December 1983 (15 months).

At the end of the experiment an exit survey was conducted to determine the residences' occupancy level over the previous 15 months and the thermostat settings of all participants.

4.3. Temperature Data

Daily temperature data for the twenty-seven localities in the study were taken from Climatological Data - Florida. This publication reports the recorded high and low temperatures for each day of the year.

4.4. Income Point Estimates

In the initial market survey conducted by FPL, participants indicated their income level by answering which of six categories they belonged to. For estimation purposes, point estimates for each category must be made. The most obvious point estimate would be the mid-point of each category. This works fine (and is employed in this analysis) for the first five categories. But since the sixth category is open-ended some other method must be employed. The standard approach to dealing with categorical income data is to estimate (using ordinary least squares) the parameters of a Pareto cumulative distribution,

$$F_x(X) = 1 - \left(\frac{k}{x}\right)^A, \text{ where } k > 0,\ a > 0,\ x \geq k.$$

This process yielded estimates of 1.059823 for A and 1.8626691 for k. The representative level of income for those households in the highest bracket is set to the median level of income above $45,000. The mean over this interval is inappropriate because of the thickness of the tail of a Pareto distribution. A cumulative distribution must be used since the categories vary in width.

Table 4.2. Income Frequencies and Representative Levels

Income Bracket	Frequency (471)	Representative Level
< $10,000	23	$ 5,000
$10,000 - $19,999	86	$15,000
$20,000 - $29,999	120	$25,000
$30,000 - $39,999	93	$35,000
$40,000 - $44,999	41	$42,500
≥ $45,000	108	$86,500

The utility maximization model assumes income is completely disposable. No specific tax information was provided, but in order to more closely approximate after-tax income, an average tax rate of 15 percent is assumed for all income brackets except the lowest one.

Most studies that deal with thermal comfort expenditures adjust after-tax income for the cost of a "subsistence" level of comfort. This type of adjustment, however, need not be made in this case.

This is so because cooling is generally considered a luxury while heating is considered a necessity. But in Florida (especially in South Florida where a large majority of the participants reside), outside temperatures seldom drop low enough (for long enough) to make a significant difference in disposable income. Further possible adjustments to income will be discussed in section 4.6 on electricity price considerations.

4.5. Thermostat Setting Point Estimates

Like income, indoor thermostat settings were recorded into categories, thus point estimates for each category were necessary. Whereas for income the highest category is open-ended, for thermostat setting both the lowest and highest categories are open-ended. So the median values of the highest and lowest intervals must be estimated. As with the income data, the mid-points of the closed-ended intervals are the representative levels for those intervals but

some distribution function must be used to estimate the other two intervals.

The Normal distribution was used. The participants were asked to identify one of four categories for summer (night and day) settings and one of five categories for winter (night and day) settings.

Therefore, there were three and four observations of the two cumulative distributions respectively. Since there are two parameters to be estimated (the mean and standard deviation), we had one and two degrees of freedom for the respective models. Using OLS we estimated the linear equation

$g = \frac{x-\bar{x}}{s}$, where g is the number of standard deviations (s), x is from the mean ($\bar{x}$). For the summer settings, the results were

$$s = 2.93,\ \bar{x} = 78.43°.$$

For the winter settings, the results were

$$s = 4.48,\ \bar{x} = 71.01°.$$

These estimates lead to the following point estimates:

Table 4.3. Summer Settings

Thermostat Setting	Frequency (/809)	Representative Setting
$\leq$ 73°	36	72.6°
74° - 76°	142	75.0°
77° - 79°	335	78.0°
$\geq$ 80°	294	81.1°

Table 4.4. Winter Settings

Thermostat Setting	Frequency (/781)	Representative Level
$\leq$ 64°	67	63.3°
65° - 67°	60	66.0°
68° - 70°	268	69.0°
71° - 74°	212	72.5°
$\geq$ 75°	174	76.5°

Interestingly, the midpoint between the average winter thermostat setting and the average summer thermostat setting is 74.72°F, which is extremely close to the reportedly ideal ambient room temperature of 75°F.

4.6. Electricity Price Considerations

Although customer responses to electricity price changes are not the main focus of this study, fuel prices are a major determinant of appliance usage cost. As mentioned previously, a major difference between this study and others is the ability to account for a nonlinear budget constraint. For most applications of the utility maximization model, exogenous prices lead to linear budget constraints. But as with most electricity rate structures, the price per kilo-watt hour (KWH) is not constant as quantity consumed increases. Thus a linear cost function is even less likely than most studies presume.

The FPL rate structure is presented in Table 4.5. The prices in this table do not include any tax surcharges that may be charged by the various municipalities. For the 1982-1983 period, the average surcharge was approximately 1.2μ/KWH.

Information on the exact prices paid by each customer was provided by FPL. Since different municipalities charged different levels of taxes and also since many customers paid no surcharge at all, customer responses to varying prices have been measured.

The five dollar monthly fixed charge represents an adjustment to disposable annual income of sixty dollars, but since income was measured in ten-thousand-dollar intervals, this minor refinement was deemed unnecessary.

Table 4.5. FPL Residential Rate Structure

	Billing Year	
Rate Components	1982	1983
Fixed Charge ($/month)	5.090	5.150
Energy Charge (μ/KWH)		
First 750 KWH	5.599	5.842
Over 750 KWH	6.617	6.842

4.7. Meter Readings Adjustments

HVAC systems are either of the split system or package system variety. Split systems (which account for over eighty percent of the systems owned by the experiment participants) have outdoor units, which contain a compressor, a condensor coil, and an outdoor fan. This unit is connected to the indoor unit via two refrigerant lines (supply and return). The indoor unit has an evaporation coil and a fan that forces warm indoor air past the coil which absorbs heat into the continuous supply of liquid refrigerant that circulates through it. Package systems (which are like window units in design) incorporate both the indoor and outdoor components into a single box or package.

The HVAC meters measured only the electricity used by the outdoor units for split systems. Thus an upward adjustment must be made for these systems. According to researchers at the Research Triangle Institute, a close approximation to the necessary adjustment can be calculated by the following equation.

$$f = x/(x-w),$$

where

$f \equiv$ multiplication factor,

$x \equiv$ ratio of the system design capacity rating (in BTUs per hour) to the EER rating, where both ratings are determined at design conditions, and

$w \equiv$ wattage of the indoor fan.

The design capacities and the EER ratings were recorded in the market survey. Wattage estimates for indoor fan motors were approximated by FPL engineers and were based on typical motor horsepower ratings for indoor fan motors in systems of various capacities.

4.8. Missing Observations

The method of dealing with missing observations employed in this study is the modified first-order regression method. Under this method all observations with missing values for the endogenous variables (thermostat settings and electricity consumption) are dropped. Missing values for exogenous variables are estimated from the values of the other observed exogenous variables.

For the data set at hand, the only exogenous variable for which there are some missing observations is income. The results of using OLS to regress income on the other exogenous variables (for participants where income was recorded) are in Table 4.6.

4.9. Observation Exclusion Criteria

Since there was only one meter measuring the electricity consumption for each HVAC system, which both heated and cooled each residence, some criterion for separating the heating energy consumption from the cooling energy consumption must be adopted. For the cooling subset of observations, only those billing months in which the recorded daily

Table 4.6. Exogenous Variables Regression Coefficients

	Cooling Subsample	Heating Subsample
Intercept	-1636.760000	-2526.020000
SQFT	.763142	.791964
CAP	.033916	.033940
INSUL	17.835060	16.453484
TEMP	3.716637	5.592623
NO-6	-67.404953	-36.496437
N7-21	74.267249	86.644545
N22-64	280.636697	271.211747
N65	-83.872666	-96.984773
HAGE	-14.091655	-13.408659
EER	-85.858621	-
COP	-	119.233860
NHEAT	-	-124.286878
NFAN	105.433067	-
PRICE	16761.770000	17941.190000

Where

SQFT = Square Footage of House,
CAP = Capacity of HVAC System (BTUs/hour),
INSUL = Insulation R-value (prior to experiment),
TEMP = Average Daily Mean Outdoor Temperature,
NO-6 = Number of people 6 years or younger,
N7-21 = Number of people between 7 and 21 years old,
N22-64 = Number of people between 22 and 64 years old,
N65 = Number of people 65 years and older,
HAGE = Age of house,
EER = Energy efficiency ratio,
COP = Coefficient of Performance,
NHEAT = Number of space heaters,
NFAN = Number of paddle fans,
PRICE = Price of one KWH of electricity.

temperature low did not drop below 50°F were included. For the heating study, only those billing months in which the daily temperature high did not exceed 80°F were included. Thus the two subsamples are not mutually exclusive nor do they collectively exhaust all the observations of the meter readings.

The reasons for this are that for certain months in Florida, outdoor temperatures are such that the HVAC systems are barely used. Thus the cost of comfort at these times is virtually zero. These "shoulder" months, as they are called, help establish the intercept terms of the cost functions.

It must be noted, however, that for the cooling subset, the signs and significance of the estimated parameters were greatly improved when months in which outside temperatures were high and no HVAC activity was recorded were excluded. Thus those observations were not included in the final cooling study data subset.

Also in Florida, during the winter there are months in which both heating and cooling are employed. That the subsamples do not collectively exhaust all the meter observations is due to my effort to exclude all months in which both heating and cooling were employed.

Another exclusion criterion is with respect to heat pumps. A heat pump provides both heating and cooling. At temperatures above the "balance point" (between 35°F and 40°F), heat pumps can extract enough heat from the outdoor

air to maintain comfortable indoor temperatures. Below that point, heat supplied by the oudoor unit is supplemented by heat from some backup source to meet heating requirements, usually a set of resistance heating coils, similar to a conventional electrical furnace.

The meter readings do not reflect the energy consumption of such backup systems. Therefore, heat pump participants were excluded from the heating subsample.

Another exclusion criterion that proved to be necessary was that of households which either adjust their A/C thermostat settings or turn off the A/C system completely when their houses are not occupied. These are essentially unobserved variations in an endogenous variable (level of comfort).

4.10. Conservation Investment Costs

A majority of the high-efficiency A/C and heat pump units were manufactured by the Carrier Corporation. Since the market for HVAC systems is fairly competitive, the retail price list for Carrier systems will be used to estimate the cost to each customer of purchasing and installing the units, had they purchased them for themselves.

Based on a telephone conversation with Doug Murphy, a sales representative with a local (Gainesville) Carrier dealer, the equipment and installation charges for their lowest and highest capacity high efficiency A/C and heat pump units are as shown in Table 4.7.

Table 4.7. Carrier Retail Prices and Installation Costs

A/C Capacity (BTUs/hour)	
18,000	45,000
$1,855	$3,075

Heat Pump Capacity (BTUs/hour)	
17,000	47,000
$1,675	$2,990

The EER ratings for the A/C system and the heat pump system are 10.25 and 8.65 respectively. Each system is designed to have a useful life of 10 years.

For ceiling insulation, the industry rule of thumb for material and installation cost is 1.5 cents per R-value per square foot. Therefore, the cost of installing R-19 of insulation in a 2,000 square-foot home would be approximately $570.

CHAPTER V

ECONOMETRIC METHODOLOGY AND RESULTS

5.1. Introduction

This chapter describes the econometric technique employed and reports the results of both the heating and cooling study. The economic analysis of the results is left for Chapter 6.

5.2. Functional Form

As with econometric studies, one would wish to be able to use a flexible functional form that contained few implied assumptions about the behavior being analyzed but also lent itself to relatively uncomplicated estimation procedures. In the normal demand-supply system of which my system is a variation, there are few alternative functional forms from which to choose. When added to the normal restrictions, the non-linear budget constraint reduces the possible functional forms even further.

The normal procedure when estimating exact consumer's surplus is to assume a particular functional form for the indirect utility function which implies a particular functional form of the Marshallian demand function. Most of these utility functional forms (such as the trans-log

function) lead to demand functions which are either difficult to estimate econometrically or are so complicated that reasonable results are difficult to come by.

Hausman (1981) made some progress in this area when he performed the reverse procedure of determining the functional forms of the indirect utility function implied by linear and log-linear demand functions. They are respectively

$$v = \exp(-\delta p)(Y + (\alpha p + \frac{\alpha}{\delta} + \theta\gamma)/\ \delta), \tag{5.1}$$

and

$$v = Y^{\phi} - P^{\delta}\exp(\theta\gamma), \tag{5.2}$$

where Y = income,

P = price of the good,

and γ = a vector of socio-economic variables.

Since in my system the indirect utility function is not a function of price but of the variables that determine marginal cost, by substituting the log-linear term $\prod_j k_j^{k_j}$ for P^{δ} in equation (5.2) we get,

$$v = Y^{\phi} - \prod_j k_j^{k_j} \exp(\theta\gamma), \tag{5.3}$$

where the k_j's are the exogenous variables (other than quantity) that determine marginal cost. When a Cobb-Douglas production function is chosen for comfort, the system to be estimated becomes

$$\text{Cost} = P_E(\prod_j k_j^{\beta_j}) Z^{\alpha}, \tag{5.4}$$

and

$$\text{CCF:} \quad Z = (\prod_j k_j^{\frac{k_j-\beta_j}{\alpha}}) \, P_E^{\frac{\delta-1}{\alpha}} \, Y^{\frac{1-\phi}{\alpha}} \exp(\theta\gamma). \tag{5.5}$$

From the log-linear estimation of these two functions the UMB and indirect utility parameters can be derived. Clearly these functional forms have their drawbacks, for instance the Cobb-Douglas production function assumes a constant elasticity of substitution of 1. Yet few other functional forms allow for the marginal cost to be non-constant and dependent on the level of the other exogenous inputs. As for the indirect utility function, many functional forms can be chosen that conform to Roy's identity but the implied functional form for the UCCFs are often intractable.

For instance when the indirect utility function,

$$v = (\prod_j k_j^{k_j} P_E^{\delta}) Y^{\gamma}, \tag{5.6}$$

is coupled with the Cobb-Douglas cost function the implied UCCF is,

$$Z = [(\frac{-k_j Y}{jA\beta_i P_E})/[(\sum_j k_j \ln k_j) \prod_j k_j^{\beta_j} + \delta(\ln P_E) \prod_j k_j^{\beta_j}]]^{1/2} \quad (5.7)$$

The complicated nature of this functional form makes it unlikely that any tractable results can be attained. Indeed when we attempted to estimate this same functional form using a non-linear estimation method, the computer program was not able to complete the task even after several attempts were made to reduce the number of parameters to be estimated and the time limit was increased. Since the results were not expected to be particularly useful, further expenditure of limited computer funds was not deemed worthwhile.

For the Cobb-Douglas cost function another modification was necessary since insulation, one of the exogenous variables, was often observed to be zero. Since the log value can not be calculated for zero, a one was added to the observed R-value for all participants.

5.3. Estimation

The econometric method employed here was the three-stage least squares estimation technique. This system of equations technique was necessary since the thermostat setting (the inverse of which is the measure of thermal

comfort) is an endogenous variable which appears in the right-hand side of the cost function.

When estimating a system of equations such as this, there is often a question of whether two-stage least squares or three-stage least squares should be employed. The conventional wisdom is that three-stage least squares should be used unless: (1) there are too few observations to allow the asymptotic properties of three-stage least squares to take effect or (2) one of the equations is so misspecified that this misspecification may be propagated to the other equations. Due to the simplicity of system and the large number of observations (for the cooling study), three-stage least squares was deemed appropriate. As it turns out, when two-stage least squares was tried the results were virtually identical to the three-stage least squares results.

For the heating study, the results were very poor (see Table 5.1). Out of the nearly seven thousand monthly observations from five hundred households only ninety-nine observations passed the exclusion criteria. Attempts to liberalize the exclusion criteria only produced less likely results. If the cost parameters are to be believed, then one would cut heating costs by increasing one's thermostat setting. Also insulation would have a negative marginal product.

Apparently, since the participants in the experiment were so heavily concentrated in south Florida, there were

Table 5.1. Heating Study Estimation.

	Estimated Parameters (t-statistics)	
	Cost	UCCF
Intercept	8.43 (2.58)	4.31 (11.77)
COMF	-2.0 -(2.9)	.--
INSUL	.005 (1.60)	-.001 -(1.38)
TEMP	.24 (.98)	.14 (2.18)
PRICE	.31 (1.08)	.24 (3.07)
SQFT	-.003 (-.04)	.04 (2.06)
CAP	-.02 (-.23)	-.02 -(.67)
HAGE	.08 (3.78)	-.0005 -(.09)
INCOME	.--	-.02 -(2.64)
NHEAT	.--	-.02 -(1.06)
NO-6	.--	.02 (1.18)
N7-21	.--	.02 (2.29)
N65	.--	.04 (3.58)

Weighted R^2 for the system = .3116
COMF = thermostat setting.
No. of Observations = 99.

just not enough months when heating was exclusively required. Due to the poor results from the heating subsample, no further analysis of the welfare effects of increased insulation during heating months was possible.

The cooling subsample provided better results (see Table 5.2). The signs of all the parameters in the cost function were as expected. Not all of the signs of the parameters of the UCCF are as expected but the model is such that it is not always clear which sign each parameter should have. For instance, the exponential parameter for insulation in the UCCF is negative, which indicates that the more insulation a household has (and presumably the smaller the cost of cooling) the less comfort they consume. More will be said about this in the final chapter.

The R^2 value for the system and the significance of some of the parameter estimates are not particularly impressive. A possible explanation for this is the cross-section nature of the data sample. Also comfort, the dependent left-hand side variable in the UCCF, had to be estimated from categorical observations. Had the thermostat setting been observed directly (or even better, if indoor temperature had been observed) perhaps the fit and significance of the estimates might have been better.

Particularly disappointing are the significance of the insulation and energy-efficiency ratio parameter estimates in the cost function. But the purpose of this study is not to prove in which direction insulation and high-efficiency

Table 5.2. Cooling Study Estimation With Name-Plate EER.

	Estimated Parameters (t-statistics)	
	Cost	UCCF
Intercept	-14.63 (-.69)	-4.58 (-57.52)
COMF	12.95 (-3.52)	---
NEER**	-.17 (-1.09)	.02 (3.65)
INSUL	-.06 (-1.26)	-.003 (-2.4)
TEMP	14.59 (27.2)	-.001 (-.07)
PRICE	1*	.003 (.23)
SQFT	.44 (3.65)	.01 (4.38)
CAP	.45 (3.76)	.004 (1.22)
HAGE	-.09 (-2.45)	.006 (7.34)
INCOME	---	.006 (4.87)
NFAN	---	-.003 (-7.55)
NO-6	---	.003 (2.24)
N7-21	---	-.0008 (-1.42)
N22-64	---	-.001 (-.96)
N65	---	.004 (3.26)

Weighted R^2 for the system = .3000
COMF = inverse of thermostat setting.
No. of observations = 1535.
*Assumed, not estimated.
**Name-Plate EER.

air-conditioning push cooling cost. What is hoped is that the parameter estimates are the best estimates of the correct value of the parameters attainable inspite of the high "noise" level present in this data sample.

An interesting phenomenon observed was that when the EER rating established by the air-conditioner manufacturer was compared to the EER rating by the FPL engineers from a field test of the participants, the actual EER rating varied widely from the name-plate EER rating. When regressed on the name-plate EER, the actual EER had an intercept term of 1.62 and a slope parameter of .56. The R^2 value was .1326. This indicates that the name-plate EER is not a very good estimate of the actual EER and that for high values of name-plate EER (around 10) the actual EER is quite smaller (around 7). This discrepancy is likely due to improperly installed systems rather than from manufacturer error.

In fact the actual EER had a smaller parameter estimate than name-plate EER when used in the regression (and slightly more significant). But when included in the UCCF, the actual EER parameter was positive (see Table 5.3) where the name-plate EER parameter was negative and quite significant. This indicates households were basing their cooling decisions primarily from industry supplied data and not from actual cost savings. More about this topic will be discussed in the following chapter.

Table 5.3. Cooling Study Estimation With Actual EER.

	Estimated Parameters (t-statistics)	
	Cost	UCCF
Intercept	-11.71	-4.54
	(-.69)	(-56.96)
COMF	12.96	---
	(-3.48)	
AEER**	-.09	-.003
	(-1.16)	(1.3)
INSUL	-.06	-.003
	(-1.40)	(-2.12)
TEMP	14.6	-.003
	(27.23)	(-.22)
PRICE	1*	.004
		(.4)
SQFT	.45	.01
	(3.69)	(4.33)
CAP	.43	.006
	(3.63)	(1.68)
HAGE	-.87	.006
	(-2.5)	(7.06)
INCOME	---	.006
		(4.74)
NFAN	---	-.003
		(-7.16)
NO-6	---	.004
		(2.76)
N7-21	---	-.001
		(-1.69)
N22-64	---	-.001
		(-1.06)
N65	---	.004
		(3.16)

Weighted R^2 for the system = .2985
No. of observations = 1526.
*Assumed, not estimated.
**Actual, not name-plate EER.

5.4. Experimental Design and the Endogeneity of Capital

As was detailed in Chapter III, the purpose of this study is to estimate, what amounts to, a short-run demand function for comfort. In the short-run, the level of capital investment is assumed fixed. But to say that the level of capital is exogenous, that is, determined outside of the utility maximization model, is not exactly the same thing. Certainly, the level of capital investment for those households that did not receive "gifts" from FPL (the control group) is endogenous to their income level, their price of electricity and so forth. The question is, can a short-run model which assumes capital is fixed and exogenous, in the econometric sense, be estimated correctly?

Given the RECD data set, the obvious solution would be to estimate a third equation with capital level as the dependent variable. But since, for the experimental group the capital level is exogenous, in the true sense of the word, a straight-forward systems of equations estimator (such as two-stage least squares or three-stage least squares) will not suffice. A modification of the econometric technique would be necessary. As it turns out, the level of capital investment (EER) for the control group averaged 7.2 with a standard deviation of .93. This indicates that 70% of the control group's investment levels ranged between 6 and 8 and very rarely did the investment level reach 10. For the control group, the correlation coefficients between the income category and both name-plate

EER and actual EER were both less than .08. It is therefore unlikely that the investment level was highly sensitive to income or some other variable.

It is obvious that the RECD project experiment was not designed with the present model in mind. Had such a model been considered, the most appropriate method would have been to give all the participants new appliances, some high-efficiency ones, some low-efficiency ones. That way, the level of capital investment would be truly exogenous. But it should be mentioned, the cost of such experiments could possibly the very high. Also, the related regulatory body may be unwilling to allow the reduction of the efficiency level of a given household.

5.5. Sensitivity of Model to Choice of Comfort Index

As mentioned in Chapter III, the choice of the comfort index for cooling to be the inverse of the thermostat setting is somewhat arbitrary. To determine if a change in this choice of index made a significant difference in the estimated values, another index was employed. The new index is 100 minus the thermostat setting (see Table 5.4).

The estimated amounts for the new index were virtually the same as for the old index. Even the standard errors of the coefficients and estimated changes of predicted amounts were essentially unchanged. This indicates that the model is probably not sensitive to the choice of comfort index.

Table 5.4. Cooling Study Estimation With New Comfort Index

	Estimated Parameters (t-statistics)	
	Cost	UCCF
Intercept	-80.14	2.34
	(-21.76)	(8.27)
COMF**	3.95	---
	(3.67)	
NEER**	-.18	.054
	(-1.11)	(3.51)
INSUL	-.05	-.01
	(-1.09)	(-2.64)
TEMP	14.61	-.009
	(27.04)	(-.17)
PRICE	1*	.009
		(.24)
SQFT	.43	.05
	(3.48)	(4.29)
CAP	.45	.01
	(3.73)	(1.13)
HAGE	-.09	.02
	(-2.56)	(7.34)
INCOME	---	.02
		(4.87)
NFAN	---	-.009
		(-7.2)
NO-6	---	.01
		(2.47)
N7-21	---	-.002
		(-1.15)
N22-64	---	-.003
		(-.66)
N65	---	.02
		(3.67)

Weighted R^2 for the system = .2989
COMF** = 100 - thermostat setting.
No. of observations = 1535.
*Assumed, not estimated.

CHAPTER VI

ANALYSIS AND CONCLUSIONS

6.1. Introduction

This chapter presents the economic analysis using the model presented in Chapter 3 and the econometric results from Chapter 5. After the criteria for the choice of the decision variable are discussed, comparisons are made between the change in consumer's surplus, cost effectiveness, the actual reduction in cost, compensating variation and equivalent variation. The chapter concludes with a discussion of avenues for future research and the policy implications of the findings of this dissertation.

6.2. The Decision Variable

As detailed in Chapter 3, to derive the marginal benefit function (both compensated and uncompensated), an exogenous variable that appears in both the (marginal) cost function and the UCC function is used. Theoretically any variable that appears in both functions can be used and will supply the results. But since, in empirical analysis, estimation bias is always a possibility, economic theory must be used to select the variable that produces the most

plausible results. This will be known as the "decision" variable.

A "first approximation" criterion is very obvious. An increase in the value of a variable that leads to a reduction in total and marginal cost should lead to an increase in the level of comfort consumed. Likewise an increase in the value of a variable that leads to an increase in total and marginal cost should lead to a decrease in the level of comfort consumed. Thus the sign of a variable's parameter estimate in one equation should be opposite to the sign of the variable's parameter estimate in the other equation. Of the five variables that have significant coefficients in both equations (SQFT, CAP, INSUL, NEER, AEER and HAGE) only NEER and HAGE pass this criterion.

Since SQFT and CAP are highly correlated with income, their positive correlation with both cost of comfort and level of comfort is not surprising. However, INSUL and AEER are not highly correlated with income. This leads to fears of some sort of selectivity bias in the choice of experiment participants, since only households that expressed a desire to be in the experiment were selected. Another possible explanation is the nature of the experiment itself. Since its primary motivation was energy conservation and not the monitoring of energy consumption, participants may have been subliminally encouraged to conserve energy (by raising their thermostat settings) more than they would have otherwise. Also since most of the variation of INSUL was induced by the

experiment, participants may not have had sufficient time (one cooling season) to regain their equilibrium.

As illustrated by Figure 6.1, the only way a reduction in marginal cost can lead to a reduction in the level of comfort consumed is by having an upward sloping UMB which is steeper than the marginal cost curve. For normal goods, of which comfort is one, the UMB should be downward sloping. And even if the UMB was upward sloping, having a greater slope than the marginal cost curve would lead to an unstable equilibrium. Therefore, the only economic explanation is that when the experiment participants' marginal cost curves shifted rightward, there was a concomitant leftward shifting of the UMB.

Th leftward shifting may have been caused by the fact that the participants knew they were in a conservation study and their energy consumption was being closely monitored. I will call this the "fish bowl" effect. More will be discussed on this subject in section 6.5.

The next criterion for choosing the decision variable is the slope of the implied UMB. Economic theory tells us that the slope of the Marshallian demand function (or in this case the UMB) is negative for a good thats consumption is positively correlated with income (i.e., a normal good). Since comfort is a normal good, the UMB should be downward sloping.

For the model used here, the sign of the exponent for the level of comfort in the UMB function determines the sign

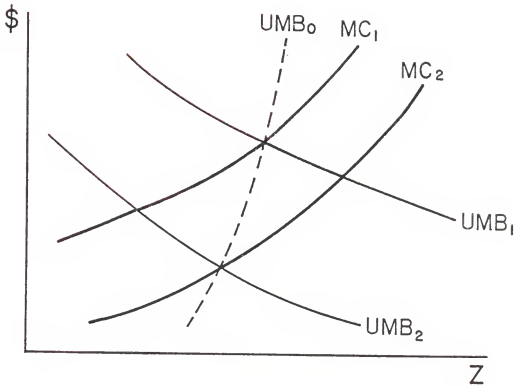

Figure 6.1.

The Observed Marginal Benefit Curve With Insulation.

of the slope. The value of the comfort exponent in the UMB function (ϕ) is

$$\phi = \frac{\alpha k_i}{k_i - \beta_i} - 1, \tag{6.1}$$

where α = the comfort coefficient in the cost function,

β_i = the decision variable coefficient in the cost function,

and k_i = the decision variable coefficient in the indirect utility function.

If EER were the decision variable, ϕ would equal .9355768. If HAGE were the decision variable, ϕ would equal -2.5862013. Thus HAGE is the only variable to pass all the criteria. With a standard error of 4.6, there is little confidence in the sign of this coefficient. But in order to illustrate the methodology, we will carry-on with the analysis. It should be kept in mind however, that the point estimates are subject to large variation.

The positive slope of the UMB, using NEER as the decision variable, results from the increase in the level of comfort consumed being greater than can possibly be justified by the observed reduction in marginal cost.

As illustrated by Figure 6.2, the level of comfort consumed increased as marginal cost decreased, but the observed UMB, UMB_o, was upward sloping and not as steep as the marginal cost curve. The only plausible economic

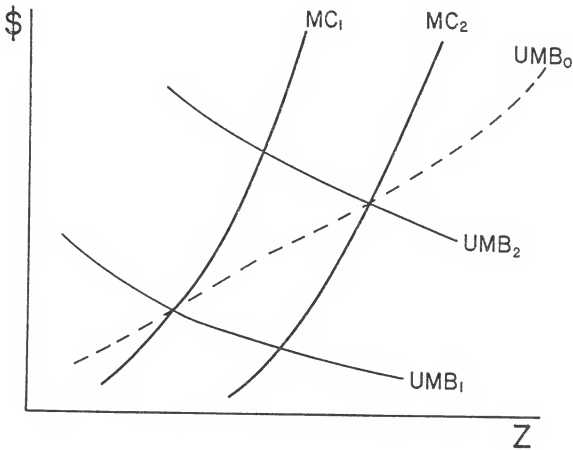

Figure 6.2.

The Observed Marginal Benefit Curve With NEER.

explanation is that the actual UMB shifted rightward. The participants that received high-efficiency air-conditioners apparently anticipated a much greater cost reduction than they actually experienced. It is interesting that when actual EER was used in the regression equations instead of name-plate EER, the UCC coefficient had the opposite sign, but was much less significant. This indicates that the households were basing their consumption decisions more on the expected cost reduction than the actual cost reduction. It is probably preferable not to draw conclusions from economic decisions based on bogus information. This supports the suspicion stated above that, after one cooling season, the households had not regained an equilibrium after the installation of the conservation equipment.

The fact that HAGE (the age of the house) renders plausible results lends more support to the disequilibrium theory. Any cost saving housing characteristics that are correlated with HAGE (such as tree shade, etc.) have been well established for a long period of time. The use of HAGE as a decision variable, therefore, does not tell us how the households actually reacted to the conservation program, but how rational households <u>will</u> react to cost reductions. Thus the usefulness of this model is enhanced since it is now used to predict.

6.3. The Change In Consumer's Surplus

From the estimation procedure done in Chapter 5, a welfare analysis of any hypothetical conservation program can be performed. For purposes of illustration, the mean values of the variables in the data set will be used. The mean values for the cooling subsample are

INCOME	= $2000 per month,
EER	= 8,
INSUL	= 12,
SQFT	= 1900,
CAP	= 38,500,
HAGE	= 11,
PRICE	= .079,
NFAN	= 1.75,
NO-6	= .25,
N7-21	= .9,
N22-64	= 1.76,
N65	= .38,
and TEMP	= 78.5.

From these mean values, using HAGE as the decision variable, the functions of the model become:

$$\text{Cost:} \quad C = (5.85 \times 10^{24})(\text{HAGE})^{-.09} \cdot (\text{COMF})^{12.95}, \tag{6.2}$$

$$\text{and} \quad \text{UCCF:} \quad \text{COMF} = .013(\text{HAGE})^{.006}, \tag{6.3}$$

From these two equations we can calculate

$$\text{Marginal Cost:} \quad C_Z = (9.6 \times 10^{26})(\text{HAGE})^{-.09} \cdot (\text{COMF})^{11.95} \tag{6.4}$$

$$\text{UMB} = (.24)(\text{COMF})^{-2.59} , \tag{6.5}$$

$$\text{and} \quad \text{UTB} = -.15(\text{COMF})^{-1.59} . \tag{6.6}$$

One hypothetical conservation program could be to increase the EER rating for each household to 10. Since the pre-experiment mean value for the name-plate EER ratings was 7, I will calculate the change in consumer's surplus from increasing the EER from 7 to 10.

From the marginal cost and UMB functions, I can determine that the increase in EER induced a decrease in the thermostat setting from 78.15° to 77.82°. Therefore, the change in consumer's surplus is $.091 per cooling day and the actual reduction in the average daily cost of comfort is $.01. Had the thermostat setting not been endogenous to the EER rating, as cost effectiveness studies assume, the reduction in average daily cost would have been $.089.

The induced setting change is only .33°F where the standard error is .51°F. Therefore, we again have little confidence in the predicted change. The percentage decrease in potential cost is 6% with a standard error of 5.8%. Also, the standard error of the ΔCS is approximately equal

to the predicted value. We therefore have little confidence in the point estimate.

Thus, from these calculations using mean values, it is shown that the change in consumer's surplus is 2.8% greater than the reduction in cooling cost (if thermostat setting is unchanged) from increasing the EER from 7 to 10. Perhaps even more significant is that, for rational households, the model predicts that as much as 88.8% of the potential reduction in cost will be taken up in the form of greater comfort levels.

Another hypothetical conservation program could be to increase the R-value of the ceiling insulation from 10 to 29. Such a program would induce a thermostat setting reduction from 78.1° to 77.79°.

The resulting change in consumer's surplus would be $.087 per day. The actual reduction in average daily cost would be $.009 and a potential reduction in average daily cost of $.084.

Thus, the change in consumer's surplus would be 2.7% greater than the potential cost reduction. The actual cost reduction would be only 11.2% of the potential cost reduction.

To see how efficient (from a welfare standpoint) a conservation program that gives conservation equipment to households would be, we must compare the cost of such a program to the benefit, the increase in consumer's surplus.

As was noted in Chapter IV, the cost of purchasing a high efficiency air-conditioning system and having it installed would be approximately $2,000. The expected useful life of such a system is ten years. At a 5% real discount rate, for the investment to be economically efficient, the increase in consumer's surplus would have to be at least $259 a year. Since increasing NEER from 7 to 10 only reduces cooling costs by 6% without a thermostat reduction (or increases consumer's surplus by an equal amount with a thermostat adjustment), the model as estimated suggests that only those households whose annual cooling bills were greater than $4,316 would benefit from such an investment. Since the predicted annual cooling bill for the mean household is less than $400, there is no reasonable scenario where the investment in conservation equipment would be economically efficient from the consumer's point of view. Even taking into account the large variance of the estimated percentage, the point estimate of the percentage decrease of cost is still several standard deviations from the percentage decrease necessary to make the increased investment either cost effective or economically efficient.

6.4. Exact Consumer's Surplus

To calculate the compensating variation and the equivalent variation, I must determine what change in the value of the decision variable (HAGE) will reduce marginal cost exactly the same as the changes in EER and insulation

R-value. From that information, we can calculate CV and EV using the following expenditure function,

$$e = (\bar{V} + (6.81)(\text{HAGE})^{-.009})^{1.09} \tag{6.7}$$

Using the mean values given in the previous section an increase in EER from 7 to 10 is equivalent to an increase in HAGE from 8.38 to 17.32. Therefore, CV equals $.091 per cooling day and EV equals $.092 per cooling day. Therefore, the change in consumer's surplus is only .51% less than EV and .69% greater than CV.

Likewise, an increase in INSUL from 10 to 29 is equivalent to an increase in HAGE from 9.28 to 18.48. In this case CV equals $.086 per cooling day and EV equals $.087 per cooling day. The change in consumer's surplus is .72% less than EV and .8% greater than CV.

6.5. Cost Effectiveness and the Fish Bowl Effect

As was stated in an earlier chapter, the change in consumer's surplus is either greater than or equal to the potential reduction in cooling costs. Since inducing the purchase of a new HVAC system before the old HVAC system has expired is not economically efficient, it is even less cost effective. The above calculations indicate that for the average household, an increase in the name-plate EER would only decrease the cost of cooling by 6%. This assumes the household not use its HVAC system more intensively when its

electricity bill decreased. The actual reduction in the household's cooling bill when an adjustment to the thermostat setting is allowed is less than 1%.

These calculations contradict several other studies that indicate cost reductions of as much as 30% (see section 1.2). This raises the question of why those studies have such different results than this study.

One possible explanation is the accuracy of the name-plate EER. Using AEER instead of NEER, we see that from Table 5.3, the cost and UCC functions would be

$$\text{Cost:} \quad C = (5.7 \times 10^{24})(\text{AEER})^{-.09}(\text{COMF})^{12.96}, \tag{6.9}$$

and

$$\text{UCCF:} \quad \text{COMF} = (.013)(\text{AEER})^{-.003}. \tag{6.10}$$

These equations again assume all the other variables are at their mean. Under these equations, a conservation program that increased actual EER from its pre-program mean of 5.5 to 10 would reduce cooling costs by only 5% with a standard error of about 5%. This is assuming that the thermostat setting is constant. Thus, the 6% reduction using the name-plate EER is not a bad approximation.

A much larger discrepancy arises when the thermostat setting is allowed to vary. In the UCC, the coefficients for name-plate EER and Actual EER have opposite signs. Due to the "fish bowl" effect, households actually tended to increase their thermostat settings when their systems became

more fuel efficient. Households that received an increase in name-plate EER tended to decrease their thermostat settings. This leads to an observed reduction in cooling costs from an increase in actual EER of 7% with a standard error of approximately 7%. The cost reductions were approximately 40% greater if the thermostat settings were allowed to vary.

This indicates that if behavioral considerations are ignored, the "fish bowl" effect may lead to the overestimation of the cost effectiveness of new HVAC systems. For example, in Messenger (1984), only 25 houses were included in that experiment. Each house was complete refitted, not only with a new HVAC system and increased insultion, but also with a new refrigerator, water-heater, etc. Such a complete refitting of a house was likely to have made quite an impression on its occupants. The participants might have felt inspired (or shamed) into conserving electricity much more intensively than they did before. Thus, ignoring modification of household behavior, as simple cost-effectiveness studies do, may lead to significant error in estimation.

6.6. Conclusions and Public Policy Implications

The purpose of this dissertation was to apply a utility maximization model to consumption of residential thermal comfort. By estimating what amounts to a demand function for thermal comfort (cooling), one can draw qualified

conclusions pertaining to utility-sponsored conservation program.

The utility maximization model provides us with the change in consumer's surplus as a measure of the benefit to consumers of conservation programs.

The compensating variation and equivalent variation, two more theoretically refined welfare measures than the change in consumer's surplus, are both within one percent of the change in consumer's surplus. Therefore, for cost-benefit studies of conservation programs, the change in consumer's surplus is quite adequate. However, if a measure of dead-weight loss is desired, then the approximation error of using consumer's surplus will be larger. Future studies might be able to perform a sensitivity analysis of the use of the change in consumer's surplus for measuring dead-weight losses.

The change in consumer's surplus resulting from the investment in a high-efficiency air-conditioner falls far short of the amount necessary to make the investment economically efficient from the consumer's standpoint. Despite the relatively large standard deviation of the estimated change in consumer's surplus, the point estimate would have to be underestimated by several standard deviations to make the investment economically efficient. We, therefore, have a large degree of confidence in our conclusion. Similar conclusions for investments in heat pumps and ceiling insulation could not be drawn, since part

of the benefit from these inputs occur during heating months. There were insufficient data to analyze heating consumption. Thus, for high-efficiency air-conditioners, contrary to other studies, we conclude that consumers are minimizing their long-run cooling costs and are not demonstrating irrationality. However, when such units are ready to be replaced, higher efficiency units may make economic sense.

If consumers are being charged the true social (marginal) cost of consuming electricity, then conservation programs that induce greater investment in high-efficiency air-conditioners have negative welfare results. However, since public utilities frequently do not charge the economically efficient price for electricity, the social welfare results of such programs are unclear. If the demand for electricity can be decreased and the distortionary effect of charging non-welfare optimizing prices be reduced by such programs, then it is possible that conservation programs could have positive social welfare effects. However, the income distributional impacts may be perverse in that homeowners tend to be more affluent than the average consumer.

Several other studies estimate the electricity cost savings from investment in high-efficiency air-conditioners to be approximately 30% of the initial bill. Our study finds that, with 95% confidence, the cost savings do not exceed 18%. That figure assumes that consumers do not alter

their thermostat settings when faced with lower electricity bills.

When consumers are allowed to adjust their thermostat settings (consume more comfort), 90% of the potential cost savings will be negated. However, since there is a large standard deviation for the estimated effect that a variation in the efficiency of an air-conditioner has on the thermostat setting, we have little confidence in the accuracy of this point estimate. If the thermostat setting or indoor temperature had been directly observed, instead of determined by category and via a telephone interview, the accuracy and confidence level of the estimated variation in the thermostat settings might have been substantially increased. Researchers planning future experiments should take this into account.

Households that received high-efficiency air-conditioners and increased ceiling insulation tended to consume lower levels of comfort than households that did not. The leftward shifting of the demand curve for comfort is referred to as the "fish bowl" effect. This effect might be caused by the nature of the study itself. Households that participate in conservation programs might feel pressured (or shamed) into conserving electricity more intensively than they would have otherwise. This effect indicates that cost-effectiveness studies that ignore household preferences may overestimate the actual long-run cost reductions of similar conservation programs. This can

explain, at least partially, the discrepancy between the cost estimates of this study and the cost estimates of other studies.

There are several implications for future studies and experiments. As stated previously, a more precise measure of the intensity of the use of the HVAC system would be helpful. Also, a more precise method of separating heating and cooling energy consumption could reduce the loss of information experienced in the RECD data set.

Another avenue for future research could be to conduct an experiment where all participants receive new investment equipment. This would alleviate the potential endogeneity problem alluded to earlier. Another method, using the long-run version of this model, would be to treat conservation investment as a qualitative variable. Cameron (1982) used such an econometric technique but with a linear budget constraint model. Such a study might better estimate the consumer discount rate that Hausman sought to determine.

From a more general perspective, this study casts considerable doubt on the desirability of conservation programs that induce greater investment in thermal comfort appliances. Even ignoring the increased household consumption of thermal comfort, the energy conservation benefits appear to be minimal. Perhaps future conservation programs should focus more on appliances that can not be used more intensively as their energy efficiency increases (such as refrigerators).

Of course, the desirability of such programs depends on their objective. Economists prefer welfare or economic efficiency as the best measure of the desirability of government-sponsored programs. Many noneconomists prefer to evaluate conservation programs by the level of energy they conserve. This more narrow criterion may not lead to the most desirable outcome from an economic efficiency viewpont.

As with most empirical studies, this study must qualify its conclusions. There are large variances for the estimated changes in consumption and consumer surplus, and in the model coefficients. Future experiments may be able to shed more light on this topic and improve the confidence of our estimates. It is doubtful, however, that such experiments would find conservation programs effecting thermal comfort consumption to be highly beneficial either from a welfare point of view or an energy conservation point of view.

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BIOGRAPHICAL SKETCH

John Franklin (Dick) Scoggins III was born on March 17, 1957, in Coral Gables, Florida, the third child of John F. Scoggins, Jr., and Nannette S. Scoggins. He grew up in Savannah, Georgia where he graduated from Windsor Forest High School in June, 1975, and Armstrong State College in August, 1979. After marrying his wife, Elaine, in 1979, he moved to Jacksonville, Florida, where he worked for an accounting firm and a software company before he received a Master of Arts degree in economics from the University of Florida in December of 1982. A doctoral degree is expected from the University of Florida in August, 1985.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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Associate Professor of Economics

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